WP5.2 Screening of BATs, BREFs and BEPs

STUDY ON BEST PRACTICES FOR THE OLIVE OIL PRODUCTION SECTOR FOR WASTE MINIMIZATION, WATER AND ENERGY CONSUMPTION AND VALORISATION OF THE SUB-PRODUCTS OF OLIVE OIL PRODUCTION.

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1	STUDY ON BEST PRACTICES FOR THE OLIVE OIL PRODUCTION SECTOR FOR WASTE MINIMIZATION, WATER AND ENERGY CONSUMPTION AND VALORISATION OF THE SUB-PRODUCTS OF OLIVE OIL PRODUCTION.	Samar Khalil Amal Sultan	Michael Scoullos

THE SWIM AND HORIZON2020 SUPPORT MECHANISM (2016-2019)

The SWIM-H2020 SM is a Regional Technical Support Program that includes the following Partner Countries (PCs): Algeria, Egypt, Israel, Jordan, Lebanon, Libya, Morocco, Palestine, [Syria] and Tunisia. However, in order to ensure the coherence and effectiveness of Union financing or to foster regional co-operation, eligibility of specific actions will be extended to the Western Balkan countries (Albania, Bosnia Herzegovina and Montenegro), Turkey and Mauritania. The Program is funded by the European Neighborhood Instrument (ENI) South/Environment. It ensures the continuation of EU's regional support to ENP South countries in the fields of water management, marine pollution prevention and adds value to other important EU-funded regional programs in related fields, in particular the SWITCH-Med program, and the Clima South program, as well as to projects under the EU bilateral programming, where environment and water are identified as priority sectors for the EU co-operation. It complements and provides operational partnerships and links with the projects labelled by the Union for the Mediterranean, project preparation facilities in particular MESHIP phase II and with the next phase of the ENPI-SEIS project on environmental information systems, whereas its work plan will be coherent with, and supportive of, the Barcelona Convention and its Mediterranean Action Plan.

The overall objective of the Program is to contribute to reduced marine pollution and a more sustainable use of scarce water resources. The Technical Assistance services are grouped in 6 work packages: WP1. Expert facility, WP2. Peer-to-peer experience sharing and dialogue, WP3. Training activities, WP4. Communication and visibility, WP5. Capitalizing the lessons learnt, good practices and success stories and WP6. Support activities.

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ABBREVIATIONS

BAT	Best Available Techniques
BEP	Best Environmental Practices
BOD	Biological Oxygen Demand
C/N	Carbon/Nitrogen
CaCO3	Calcium Carbonate
CBA	Cost-Benefit Analysis
CED	Cost of Environmental Degradation
CH4	Methane
CO	Carbon Monoxide
CO2	Carbon Dioxide
COD	Chemical Oxygen Demand
dB(A)	Decibel (A)
EU	European Union
Fe2O3	Ferrous oxide
FeCl3	Ferric Chloride
FeSO4	Ferrous Sulphate
H2	Hydrogen
H2O2	Hydrogen Peroxide
Ha	Hectare
IDE	Energy Sustainability Index
IOC	International Olive Council
IrO2	Iridium Dioxide
JD	Jordanian Dinar
K	Potassium
KHz	Kilo Hertz
Km	Kilometer
KV	Kilo Volt
KWh	Kilo-Watt-Hour
MENA:	Middle East and North Africa
ml	Milliliter
MnO2	Manganese Dioxide
MoE	Ministry of Environment
MW	Microwave
O2	Oxygen
O3	Ozone
OLR	Organic Load Rate

OMW :	Olive Mill Waste
OMWW :	Olive Mill Waste Water
OTS	Organic Total Solids
P	Phosphorus
PAC	Polialuminum Chloride
PC	Photo Catalysis
PEF	Pulsed Electric Fields
PMB	Biochemical Methane Potential
RAC/CP	Regional Activity Center for Cleaner Production
RuO2	Ruthenium Dioxide
SO2 :	Sulfur Dioxide
TiO2	Titanium dioxide
TND	Tunisian Dinar
TS	Total Solids
UCAIC	University of California - Agricultural Issues Center
UNDP	United Nations Development Program
US	Ultrasound
USA	United States of America
USD	United States Dollars
UV	Ultraviolet
VDP	Variable Dynamic Pressure
W	Watt

EXECUTIVE SUMMARY

This reference document on Best Available Techniques (BAT) in the olive oil industry provides an overview of the best practices in the olive oil production sector with emphasis on waste minimization, water and energy consumption and valorisation of the sub-products of the olive oil production in the Middle East and North Africa (MENA) region.

General information on the production of oil processes is provided as well as background of the economic, legislative and environmental aspects of this specific agro-industry.

Moreover, an overview of the currently practiced processes and techniques in the oil industry (pressing and continuous systems, stone removing processes, percolation, chemical separation and electrophoresis) is provided with the ensuing environmental impacts. A detailed analysis is given for the most commonly used olive oil extraction techniques, covering the traditional press and the continuous three-, two- and two-and-a-half phase systems. The report highlights the importance of the extraction technique employed as the main factor in determining the resulting by-products and clarifies the variations between the different by-products. A physical and bio-chemical profile is given.

In addition to specific currently employed/available techniques and processes for extraction, the document also examines the different steps involved in the olive oil industrial process from the reception of olives and material involved, to handling and storage, water consumption, energy consumption, pomace management, air-emissions control, vegetable water management and overall environmental management systems.

BATs are presented and the main parameters for each extraction and waste treatment system will be examined in conjunction with the specifically designed scale that reflects both the complexity and the severity these parameters entail for their management and valorisation. Accordingly, conclusions are drawn. The document concludes, with suggestions for the best practices in the olive oil production sector for waste minimization, water and energy consumption and valorisation of the sub-products of the olive oil production in the MENA region.

1. SCOPE

The scope of this document includes the whole range of activities involved in the production of olive oil, focusing on the treatment of wastes produced in olive oil production processes in the MENA region. The document, however, does not cover upstream activities related to oil production, namely the agricultural aspect of olive trees. The region covered by this document includes the Levant Mediterranean basin of Lebanon, Syria, Jordan, Israel and Palestine and the North African countries of Egypt, Libya, Tunisia, Algeria and Morocco.

In chapter 2, general information on the olive oil production sector in the MENA region, such as employed techniques, critical factors, distribution and value is provided. This chapter also covers the economic aspects of the process such as structure, trade, market demands and competition as well as the distribution aspects of the industry. In addition, the legislative framework for olive oil production in the region is briefly reviewed, focusing on key environmental issues.

In chapter 3, more details are given on the applied techniques and processes employed currently in the MENA region to produce olive oil. In specific sections the various pressing techniques, stone removing processes, percolation, chemical separation and electrophoresis of the different components of the industry are presented.

In chapter 4, the environmental impact of the industry, the wastes' characteristics and emission levels will be introduced and discussed.

Chapters 5 and 6 present the techniques used to determine the BAT/BEP. These chapters are divided according to the main elements of the process and how each element is connected to the determination of the BAT/BEP. The related elements discussed are the olive oil extraction techniques, the reception, handling and storage of by-products, the water and energy consumption, the pomace management, the air emissions control, the vegetable water management and the overall environmental management. Accordingly, conclusions are drawn in chapters 7 and 8 to present the best available techniques and practices for the management of the by-products of the olive oil industry.

2. GENERAL INFORMATION

2.1 OLIVE OIL PRODUCTION IN THE REGION

Olive oil production is a significant productive sector in the Mediterranean region. In fact, around three quarters of global olive oil production is concentrated in the European Mediterranean countries with Spain leading the list, followed by Italy and Greece. The majority of the world's remaining olive oil production (about 500 thousand tons in 2017) comes from the Middle East and North Africa. There have been some new emerging countries like New Zealand, USA, Chile, Argentina and Australia in the last decades but olive oil production remains predominantly concentrated in the Mediterranean basin. As such, the non-European section of the basin, otherwise known as the MENA (Middle East and North Africa) region is the focus area of consideration in this document. The table below shows olive oil production in the region from year 2013 till year 2017 as well as an estimated production for the year 2018.

TABLE 1: Olive oil production in the Middle East and North Africa (in 1000 tons) between 2013 and 2018

Country	2013/2014	2014/2015	2015/2017	2016/2017	2017/2018
Tunisia	70	340	140	100	280
Syria	180	105	110	110	100
Algeria	44	69.5	82	63	82.5
Morocco	130	120	130	110	140
Egypt	20	17	16.5	20	20
Jordan	19	23	29.5	20	20.5
Lebanon	16.5	21	23	25	17
Palestine	17.5	24.5	21	19.5	19.5
Libya	18	15.5	18	16	18
Israel	15	18.5	18	15	16

Source: (IOC, 2018)

As can be noted from TABLE 1, there are huge year-to-year swings in the production of olive oil across the region. This is normal in the olive oil world as the agricultural aspect of olives is dependent on many factors mainly the characteristic alternate bearing pattern of the olive tree, as well as rainfall and some culture-related practices to name but a few.

2.2 ECONOMICS AND EMPLOYMENT IN THE OLIVE OIL SECTOR

2.2.1 The sector's structure in the Mediterranean

Olive oil is a Mediterranean product of great importance, be it from a production (as seen in TABLE 1 above) or consumption point of view (Table 2 and Table 4 below). Olive oil production happens in a highly complex and diversified structure. The structure is such because it is affected by various factors, including but not restricted to variations in the overall regional (Mediterranean) production, market internationalization as well as the wide diversity of producers and producer organisations. The latter is dependent on many factors as well. To start with, producer organisations exist in countries with a wide spectrum of infrastructural and developmental frameworks, from "first world" countries of the EU to "developing" countries in North Africa and the Middle East. In addition, producer organisations vary greatly in size between and within countries, resulting in a very fragmented sector. In most of the producer countries olive oil producers tend to be medium to small firms. However, in recent years, there has been an increase in the involvement of multinational industrial bottling companies. Finally, production systems vary dramatically between and within countries.

TABLE 2: Olive oil consumption (1000 of metric tons)

Country	1990/91	2015/2016 (PREV)	Difference
Japan	4,0	60,0	1400%
United Kingdom	6,8	58,7	763%
Germany	10,3	58,2	465%
Brazil	13,5	66,5	393%
Russia	5,0	21,0	320%
France	28,0	103,0	268%
United States	88,0	308,0	250%
Portugal	27,0	74,0	174%
Turkey	55,0	124,0	125%
Spain	394,1	490,0	24%
Italy	540,0	580,8	8%
Greece	204,0	150,0	-26%
China	-	6,0	-
Total	**1.666,5**	**2.989,0**	**79%**

Source: oliveoiltimes.com accessed May 2018

For the MENA region, most of the olive mills tend to be very small to medium size enterprises. The number of mills, sizes, technologies used and location (rural/urban) for each country where such data exists are given in the following sections.

2.2.1.1 Algeria

The total production of olive oil amounts to 82.5 thousand tons in 2018.

The number of olive mills recorded was 1,953, distributed as follows (Rizou, 2012):

- 75% traditional oil mills;
- 4% super-presses;
- 21% continuous systems.

Pomace is thrown after a period of storage on the Wadi beds and then burned (Boudi, Laoubi, & Chehat, 2016).

Regarding OMWW, a survey conducted by Boudi et al. showed that it is disposed directly in nature or in sewer systems, so they end up soon after in Wadi flows (seasonal streams). Although there were few minor measures and tax charges imposed by agricultural services to reduce these effects, their impact was insignificant and random (Boudi, Laoubi, & Chehat, 2016).

2.2.1.2 Egypt

- There are 25 press mills and 48 continuous process facilities.
- The total production of olive oil amounts to 20 thousand tons in 2018.

2.2.1.3 Israel

- There are 132 olive mills, 118 of which are 3-phase, 9 are traditional and 5 are 2-phase (Aboud, 2012).
- The volume of OMWW is estimated at 120,000 m3/year.
- The volume of pomace is estimated at 30,000 m3/year.
- The production of olive oil in 2018 amounted to 17 thousand tons.

2.2.1.4 Jordan

- Approximately, 130,000 hectares of land in Jordan are planted with around 20 million olive trees, making it the country's top agricultural product.
- There are about 131 olive mills (Ministry of Agriculture, 2015). The majority of the mills are small to medium size. Around 98% of the mills use the 3-phase system with a total production capacity of 425.5 tons/hour (Mheisen, 2019). Most of them are in rural areas with 70% located in the North region.
- These mills produced more than 20.5 thousand tons of olive oil in 2018.

- The estimated yearly volume of OMWW obtained from mills amount to 150,000 to 200,000 m3. OMWW is stored in concrete reservoirs in olive mills and then using cisterns, is transported to designated evaporation ponds in each region. This system costs around 300 JD for disposal in the evaporation pond and 50 JD per olive oil gallon of 15 liters for transportation (Mheisen, 2019).
- The annual production of pomace is estimated at 35,000- 40,000 tons. Pomace is dried and pressed to form heating blocks that are used as a source of fuel and heating inside the mills. The cost of pomace treatment is 25 JD/ton (Mheisen, 2019).

2.2.1.5 Lebanon

- Olive trees occupy 5.4 % of total land surface or 8% of agricultural lands. More than 170,000 framers and growers work in the field.
- Lebanon has 492 olive mills producing 17 thousand tons of olive oil in 2018 and around 36 complementary industries including soap and coal.
- The majority of the olive mills (45.73%) are located in North Lebanon, followed by Mount Lebanon (17.48%), South Lebanon (16.67%), Nabatieh (15.45%) and Bekaa (4.67 %).
- 87% of olive mills use the traditional oil extraction method, while 10% use 3-phase decanters and 3% use 2-phase decanters.
- 80% of mills are owned by individuals while only 5% are owned by cooperatives.
- The average maximum production capacity of olive oil mills in Lebanon is 657 kg/hr.
- The annual production of OMW reaches 280,000 m3 of OMWW and 84 thousand tons of pomace.

2.2.1.6 Libya

- The total production of olive oil amounts to 18 thousand tons in 2018.
- In Libya, the olive oil industry is limited to the North-West of Libya while there are some located in the south and the eastern part of Libya (Aljamal, 2019).
- The most common technology is the traditional method, however, there are also few modern mills that use centrifugation (Aljamal, 2019).
- The pomace is used for animal feed or fermented and mixed with organic fertilizer (Aljamal, 2019).
- As for the wastewater, it is mostly stored in open concrete tanks in which sediments are trapped and can be mixed with fertilizers, while the liquid waste is discharged randomly to the surrounding environment due to the lack of control and monitoring from the government (Aljamal, 2019).

2.2.1.7 Morocco

- The production of Moroccan olive oil accounts to 5% of the Moroccan agricultural GDP and 15% in agrifood exports. Morocco’s annual production capacity is 1.5 million tons of olives (0.6 million tons is triturated by about 565 modern and semi-modern mills and 0.16 million tons is triturated by more than 15,000 traditional mills).

- There are large, medium and small scale olive mills of which 15,257 are traditional mills (production capacity 2,007 t/hr), 297 are press mills (production capacity 187t/hr) and 288 are continuous process facilities (two or three phase) with production capacity of 679t/hr (IOC Country profiles, 2012).

2.2.1.8 Palestine

- There are around 11.5 million olive trees in the Palestinian territories (West Bank and Gaza) accounting for around 77,900 hectares.
- The annual production of olives in 2018 amounted to about 85,000 tons and 19.5 thousand tons of olive oil.
- There are 274 small and medium sized olive mills, 245 of which are located in the West Bank. Most of them (89%) are located in rural areas without implementing any recorded management plan.

2.2.1.9 Syria

- In 2005, there were around 1,000 olive mills in Syria. Olive mills using the traditional press method were about 47.8%, mostly concentrated in the costal region (Tartous and Lattakia) and in the north (Aleppo and Idleb), whereas olive mills employing 3-phase decanting equipment constitute more than half (50.9%) while mills employing 2-phase decanting equipment constitute only 1.2 % (EU, MoLE, & UNDP, 2005).
- Total production of olive oil in the year 2017 amounted to 100 thousand tons.
- were generated in Syria during a high olive production year (EU, MoLE, & UNDP, 2005).
- Vegetable water is disposed of improperly to sewers, surface water courses, and lands, whereas pomace is used for secondary extraction of its oil content for use in complementary industries, as well as a fuel for heating and for exportation in bulk quantities to Turkey (EU, MoLE, & UNDP, 2005).

2.2.1.10 Tunisia

- There are 613 traditional mills, 437 press mills and 657 continuous process facilities (two or three phase) distributed in different rural geographic locations.
- Tunisia produced around 280 thousand tons of olive oil in 2018. It exports 71% of its olive oil production, and is ranked second world largest exporter after the EU.
- Around 700,000 tons of OMWW and 450,000 tons of pomace are produced per year (Gargouri, et al., 2013).
- The OMWW disposal system is based on collecting and drying it in evaporation ponds located near the producing areas (Gargouri, et al., 2013).
- Pomace from the continuous three-phase process is actually utilised as animal feed or for energy production after residual oil extraction (Gargouri, et al., 2013).

2.2.2 Trade

Global production and trade of olive oil is large and significant, especially in the whole of the Mediterranean region. In fact, global production value averages around $11 billion with the majority of it in the European Union and about $1.8 billion in production value in the MENA region. Exports from the MENA are valued at almost $1 billion, while EU exports are worth about $2 billion based on International Olive Commission data. Olive oil production and exports have been growing rapidly in the MENA region with a significant shift in exports from non-virgin to virgin oil exports (UCAIC, 2013). Below is a table detailing the production, export and import of olive oil per country by the end of year 2018.

TABLE 3: Production, export and import of olive oil in the year 2018

Country	Production (1,000 ton)	Import (1,000 ton)	Export (1,000 ton)
Morocco	140	6	15
Syria	100	0	13
Tunisia	280	0	200
Algeria	82.5	0	0
Lebanon	17	5.5	3
Egypt	20	0	7.5
Jordan	20.5	0	0
Palestine	19.5	0	4.5
Libya	18	0	0
Israel	17	4	0

Source: (IOC, 2018)
Note: 0 Nil or less than 300 tons

2.2.3 Market Forces: demand, distribution and competition

2.2.3.1 Demand

Diets and food demands are changing globally with consumers paying increasing attention to health, food quality and flavours. In that direction, olive oil consumption has been increasing over the last decades, and constitutes one of the most important dietary trends worldwide. This is especially understandable with olive oil offering a valuable source of antioxidants and essential fatty acids that are key components to a healthy human diet.

TABLE 4 shows consumption of olive oil per country, within the MENA region. The region has witnessed "stable" consumption or increase in olive oil consumption, particularly in Algeria, Lebanon and Egypt much in line with international trends.

TABLE 4: Olive Oil consumption (1000 ton) during years 2013 – 2018

Country	2013/2014	2014/2015	2015/2017	2016/2017	2017/2018 (estimated)
Morocco	120	120	120	120	120
Syria	170.5	126	104	110	100
Algeria	48.5	65	80	67	85
Tunisia	37	30	35	25	35
Jordan	25	22	29	20	24.5

Egypt	18.5	20	16,6	17	22
Lebanon	18	18	18	20	21
Israel	20	20	20	19.5	21
Libya	15	15	18	16.5	18
Palestine	15	17	17	16	15

Naturally, an increasing appetite for olive oil is spearheading a strong demand for edible oils across the MENA region, putting the sector on track to record a 5.3% compound annual growth rate by 2021, outstripping the forecasted 3.8% global average, according to Euromonitor International. Euromonitor International also reports that soaring demand for olive oil, particularly in the United Arab Emirates and Saudi Arabia, is the result of an influx of Arab and Southern European expatriates and an increase in the number of health-conscious consumers. According to the report, growing health awareness is enabling more oil brands to penetrate the market, a trend that is set to further extend consumer awareness and therefore build category sales (Hospitality services s.a.r.l., 2015). Growing tourism flows may also result in increase of olive oil consumption.

2.2.3.2 Distribution

Modern distribution channels (hypermarkets, supermarkets and discount stores) continue to be the major place of purchase of olive oil. In fact, 86% of the olive oil consumed in the region is bought at this type of premise where the range of products and brands, prices, offers and special promotions are the chief reasons for purchasing.

In the group of virgin olive oils, consumption is preponderantly (96%) of extra virgin olive oil.

Hypermarkets are consumers' preferred place of purchase for virgin olive oil, accounting for 40% of all the olive oil consumed. Supermarkets, with a 39% share of purchases, are the preference when it comes to olive oil.

Notably, around one fifth of olive oil purchases are made in discount stores.

There are exceptions to the rule however, and we can see that the majority of olive oil produced in Lebanon, for example, is sold in bulk in olive mills.

2.2.3.3 Competition

With the observed increasing demand rate and accompanying wider distribution channels, as well as the diversity and innovation in branding and bottling experienced across the olive oil sector, competition has equally increased amongst producing countries. While Spain remains uncontestably in the global pole production position (followed by Italy, Greece and Turkey), of the MENA region, Tunisia takes the first position, followed by Morocco and Algeria. However, it is Italy that takes the first place in olive oil consumption, followed by Spain and Greece and as mentioned before United Arab Emirates and Saudi Arabia are closely following behind.

2.3 LEGISLATIVE FRAMEWORK FOR OLIVE OIL PRODUCTION

Because waste generated from olive oil production is a serious environmental concern as shown in the following chapters (predominantly because of its high organic content, difficulty and expenses associated with its treatment), there has been awareness to the danger of dumping such agro-industrial waste in municipal sewers or receiving water bodies. As such, some countries have made provisions to allow a specific amount of OMWW to be used in plantations of olive trees (in specified doses and times), while some are recycled into the mills, or treated to subtract different starter compounds. However, there are rather few legislative texts that directly tackle the olive oil sector and/or the impacts resulting from the production process in the study area. Furthermore, there are international agreements signed by countries from the MENA region related to the protection of different environmental media from sources of pollution. The main important ones are the provisions of the Barcelona Convention and the Protocol for the land-based sources of pollution.

Some of the legislative texts that tackle the olive oil production and trade in the MENA region are presented below:

• Decision No DEC-18/S.ex.27-V/2016 “Revising the trade standard applying to olive oils and pomace oils”- July, 16, 2016-Tunisia:

The trade standard modifies the physico-chemical and distinguishing quality and purity criteria of each grade of olive oil and olive-pomace oil that is mentioned in the Agreement. The International Olive Oil Committee members are committed to prohibiting the use of any product labels other than those specified. It also specifies the methodology for the collection and chemical analysis of samples.

• International Agreement on Olive Oil and Table Olives, 2015 - adopted by Decision No.DEC-1/S.ex.24-V/2015 on 19 June 2015. Signed by: Algeria, Tunisia, Lebanon, Libya, Morocco and Jordan.

2.3.1 Jordan

• Instructions for the licensing and operation of olive presses for the year 2012, issued under article 16 of the Agriculture Law no 44/2002.

• Law no. 13/2015 for the control of olive mill operations.

2.3.2 Lebanon

• Ministry of Environment (MoE) Decision No. 100/1 dated July 2010: Implementation of the Guidance Note for the olive oil industry in Lebanon and the resulting environmental pollution.

• MoE Decision No. 101/1, July 2010: Environmental conditions for licensing the establishment and/or operation of olive mills.

• MoE Decision No. 102/1, July 2010: Conditions for reusing vegetable water in irrigation.

2.3.3 Syria

• Decision of the Ministry of Local Administration and Environment No. 119/N dated 24/9/2007: Environmental conditions for the licensing of olive mills.

• Decision of the Ministry of Agriculture and Agrarian Reform No. 190/T dated 5/9/2007: Mechanism for the collection and distribution of vegetable water on agricultural lands.

• Decision of the Ministry of Agriculture and Agrarian Reform No. 1214 dated 19/7/2007: Environmental conditions for olive mils (location, measures to mitigate pollution resulting from olive mill waste, penalties against violators, etc…).

2.3.4 Tunisia

• Decree No. 2013-1308 of February 26, 2013, Ministry of Agriculture: Conditions and procedures for managing vegetable water and their use in agricultural fields.

• Joint publication No. 192 dated 24 August, 2017, between Ministry of Agriculture and Ministry of Environment: Conditions and disposal methods of vegetable water to be used in the field of agriculture.

• Decree No. 2008-2036 of May 26, 2008, Ministry of Industry, Energy and Small and Medium Enterprises: Characteristics and conditions for packaging, packaging and labelling of olive oils and olive-pomace oils.

2.4 THE OLIVE OIL SECTOR AND THE ENVIRONMENT

2.4.1 Key environmental issues

The extraction of olive oil generates huge quantities of wastes that may have a great impact on land and water environments because of their high phytotoxicity. The most polluting and phytotoxic wastes are known as Olive Mill Waste (OMW). Besides being a serious environmental problem, OMW represents today a precious resource of useful for biotechnology compounds for recovery and valorization purposes. The annual world OMW in 2008 was estimated to be between 10 to over 30 million m3.

The amount and the physicochemical characteristics of the generated wastes depend on the used oil extraction system, the processed fruits and the operating conditions (added water, temperature, etc.).

The three-phase extraction systems generate a solid waste that is used to extract olive kernel oil. On the other hand, wet olive pomace (from two-phase mills) is a solid waste with a strong odour and a doughy texture that makes its management and transport difficult. It is very humid and very difficult to treat. It is generally subjected to solar drying and subsequently used to extract oil with solvents.

Olive Mill Waste Water (OMWW) is the main waste from three-phase extraction systems and traditional mills. It is constituted from vegetable water of the fruit and the water used in different stages of oil extraction.

The high phenolic nature of OMWW and its organic contents make it highly resistant to biodegradation. OMWW shows poor biodegradability and high phytotoxicity due to the presence of phenolic compounds.

Likewise, the presence of reduced sugars can stimulate microbial respiration and lower dissolved oxygen concentrations. OMWW shows higher chemical oxygen demand and biological oxygen demand values of domestic sewage, ranging from 80 to 200 g/L and from 12 to 63 g/L, respectively (El-Abbassi A., 2017).

The cost of environmental degradation from the olive oil sector in Lebanon was estimated at 13.27 million USD per season (MoE, UNDP, EU, 2007).

The following sections present a summary of the main waste streams and pollution loads generated from olive mill industry and their impacts on the environment (Niaounakis & Halvadakis, 2006) (RAC/CP, 2000).

The main waste streams generated from the olive oil processing stages and their associated environmental impacts are presented as follows:

2.4.1.1 Liquid waste

OMWW or vegetable waters (known as "Zebar" in Lebanon, Jordan, Palestine and Syria) is made up of the vegetable waters of the olives, frequently mixed with water added in the process. They present a high polluting power with toxic effect. In fact, OMWW is among the "strongest" industrial effluents with a COD level reaching, in some cases, up to 220 g/L. Uncontrolled dumping of OMWW translates into an ecological problem of considerable importance. The different sources of liquid waste generated from olive pressing are as follows:

- Washing stage: Olive rinsing water of the fruit (low pollution load);
- Extraction stage: Vegetation waters of the actual olives generated during pressing and decanting;
- Oil rinsing water generated from centrifuge during oil-water separation;

The ensemble of the three listed sources makes up the genuinely denominated "vegetable waters".

The peculiarities, which make the treatment of OMWW particularly very difficult, can be summarized as follows:

- Acidic nature with pH ranging between 4.0 – 5.5;
- High organic load (1m3 of OMWW = 100-200m3 of domestic sewage). It has been reported to be 5-10 or even 25-80 times larger than that of domestic sewage (Niaounnakis M., 2006);
- Presence of organic (5-18%), phyto and bio-toxic (due to its phenolic content) compounds which are difficult to degrade by microorganisms (long chain fatty acids and polyphenolic compounds (0.5-24g/l) such as the C7 and C9 family);
- High percentage of dissolved mineral salts and suspended solids;
- Intensive violet-dark brown to black colour;
- Very specific offensive smell;
- Seasonal fluctuations in OMWW quantity generated with high geographic scattering of mills with the majority being small scale mills.

Some of the negative environmental effects are:

2.4.1.1.1 Soil Contamination even under loosely controlled conditions

• OMWW acidity may affect physical and geotechnical soil layer properties and causes pollutant migration in the subsoil.

• Application of OMWW to soil increases the risk of groundwater contamination.

• Irrigation with high doses of OMW produces a toxic effect against several Mediterranean crops grown in an organic matter-rich soil.

2.4.1.1.2 Ground Water Pollution

Small quantities of OMWW in contact with groundwater have the potential to cause significant pollution to drinking water sources. The problem gets more serious when chlorine is used for water disinfection. Chlorine in contact with phenol reacts to form chlorophenol which is more dangerous to human health than phenol alone.

2.4.1.1.3 Surface Water Pollution

• When OMWW is disposed of in rivers, the pH alteration may cause fish deaths.

• The fat content of OMWW forms a layer on top of the water, which impedes water oxygenation and passing of sunlight, therefore preventing the normal development of fauna and flora in rivers.

The organic content of OMWW contributes to the consumption of the dissolved oxygen.

2.4.1.2 Solid waste

The different types of solid waste generated from olive pressing are as follows:

• Vegetable and earthy leftovers, from the de-leafing of the olives. This quantity is highly variable depending on the harvesting system and meteorological conditions. Literature studies (RAC/CP, 2000) states that leaves/stems/soil may constitute between 2% and 15% of the total weight of incoming raw olives. Normally, they are reincorporated into the soil as organic fertilizer, with or without previous composting.

• Conventional spent olives or pomace containing the pulp, the stone and the tegument of the olive, with a moisture level around 26%, 50% and 70% and with a fat content of around 7%, 3% and 2% for traditional, three phase and two-phase systems, respectively, (RAC/CP, 2000).

The spent olives can be put to several uses:

• Extraction of the residual oil in secondary oil extraction industry for the production of olive-kernel oil by means of an organic solvent such as Hexane or by physical extraction using decanter

• Food stuff for livestock in cattle

• Solid fuel

2.4.1.3 Air Pollution

When Olive Mill Waste Water is spread on agricultural soils, it results in the emission of sulfur dioxide (SO_2) and phenols. Total phenols emission is lower when OMWW is spread in the afternoon. As for

SO_2, it is very reactive and readily oxidizes; it forms sulfuric and sulfurous acids that are deposited as acid rain. These may be transported over long distances, due to their long dwelling time in the atmosphere. The former causes fermentation phenomena when vegetable water is stored in open ponds or discharged on soil or into natural water bodies, producing methane and other pungent gases such as hydrogen sulfide in case of pond evaporation or heavily polluted soils and water. Similarly, offensive odour generation occurs from anaerobic decomposition of oil cake with high moisture content (especially in the two-phase system) at the bottom layer of the stored pomace. Leachate generated from prolonged storage of pomace also highly contributes to this odour generation (Niaounakis M., 2006).

Moreover, emissions from mill's equipment and vehicles transporting raw material and end products add to the air pollution load in and around the mill.

2.4.1.4 Noise Pollution

Noise pollution associated with mills' operation is a major occupational hazard. Noise levels inside mills can easily exceed 90 dB(A) due to the use of machinery that produces high noise levels such as the grinder, decanter, leaf stripper and centrifuge (actual field audit measurements, 2006 and 2017). Outdoor noise level could become a public nuisance if the mill is located within a residential area and noise pollution is not properly controlled, especially during night time.

2.4.1.5 Public Health and Safety

The presence of olive mills in the close proximity to – or within – residential areas can be a concern in terms of public health and safety, due to:

• The storage of vegetable water in open cisterns/pits, which could attract vectors and insects, and constitutes a hazard (polluting power with toxic effect);

• The storage of pomace in open areas, which constitutes an odour nuisance; and

• Increased traffic during the olive season, resulting in an increased risk of accidents, in addition to air and noise pollutions.

2.4.1.6 Olives and other materials' reception, handling and storage

To maintain the quality of virgin olive oil, the olives should be processed within twenty-four hours after harvesting. A thin, 30-40 cm thick layer of olives should be stored in perforated boxes on pallets, in order to minimize the fermentation processes, which underlie not only the formation of sensory defects, but also water condensation on the surface of the olive skin, which can promote the attack by moulds. Perforated boxes and pallets are also the most suitable media to transport the olives from the olive grove to the mill (Servili, Taticchi, Esposto, Sordini, & Urbani, 2012) (Servili, Taticchi, Esposto, Sordini, & Urbani, 2012). Another aspect which affects the storage premises is related to the handling of the pallets or boxes. This process must be done by avoiding the use of forklift trucks run by petrol engines, which produce polycyclic aromatic hydrocarbons. These compounds can contaminate the olives, and subsequently the oil (Angerosa, et al., 2004).

To wrap up, the challenge with managing the OMWW is to find environmentally sound and economically feasible solutions. This is not a small achievement. In fact, this has proven difficult to achieve because of the high organic loads of OMWW, coupled with high COD and BOD ratios, any biochemical treatment requires high capital and operating cost units. In addition, biological treatment of OMWW has been disregarded because of the bacteria-toxic organics released from the broken seeds. To top it all, the alternate bearing cycle of the trees, coupled with sporadic, geographically spread out small size low budgeted production sources, make a central treatment facility hard, if not impossible in certain situations, to establish.

2.4.1.7 Potential of using OMWW

Despite the negative environmental effects of vegetable water, and the perceived difficulty in the treatment of such type of wastes, emerging research indicates that these wastes can become economic assets. With proper treatment and right doses, OMWW can be transformed into soil conditioner, compost, biomass fuel, or provide starting material for anti-oxidants, biogas fuel and enzymes. In addition, if properly controlled and applied in doses less than 25-50 m3/ha OMWW can be used for direct irrigation.

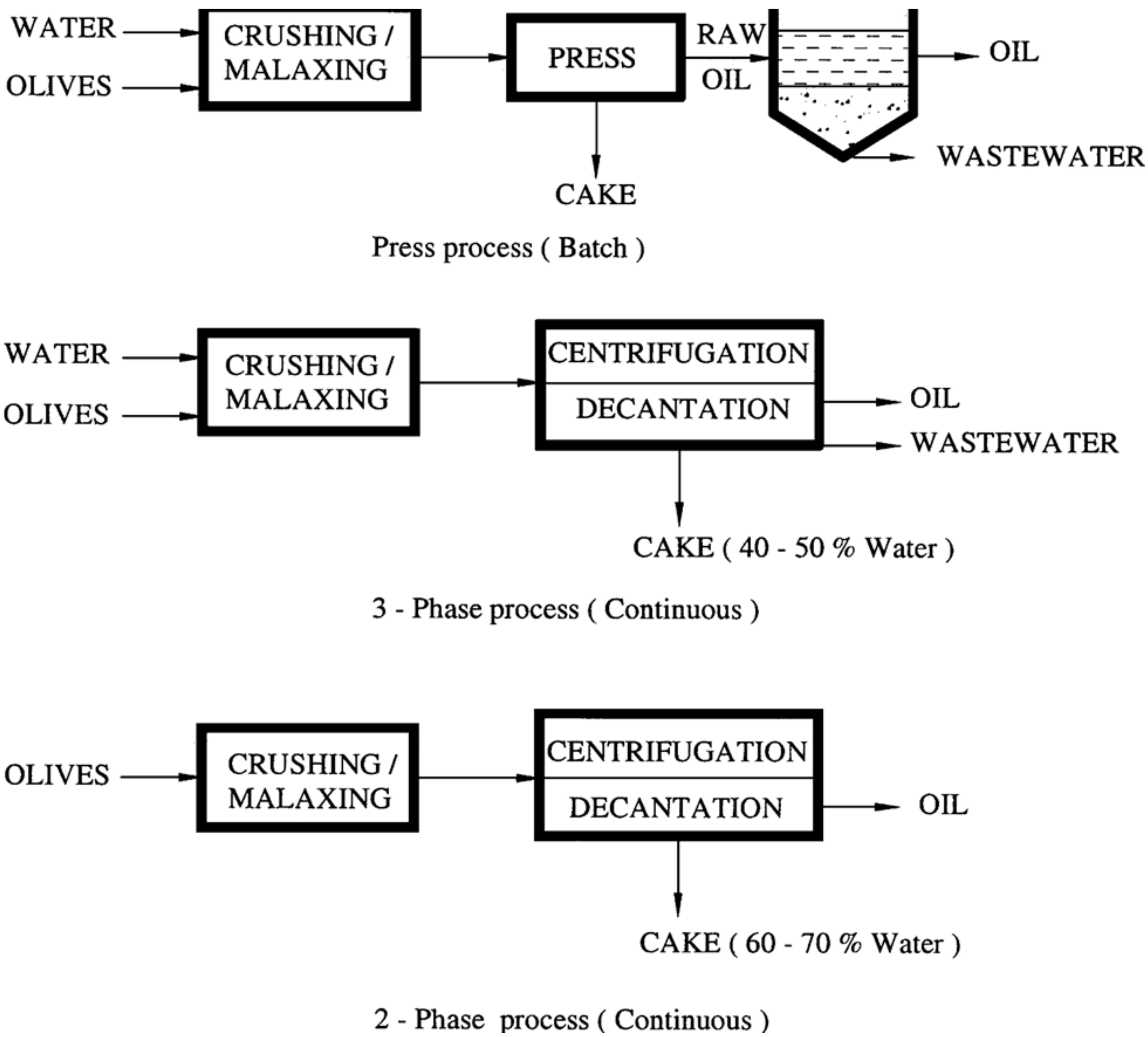
In fact, OMWW can be treated and most importantly reused for a variety of purposes if properly treated, controlled and applied. It is imperative to understand the production systems and subsequent variations in OMWW composition to be able to formulate an informed decision on what solution or practice to apply in any specific situation.

Therefore, in the following chapter, we describe the various steps and techniques used in currently operating olive mills.

3. APPLIED PROCESSES AND TECHNIQUES

Olive oil is produced in what is known as mills. In currently existing mills, extraction of oil follows the simple outline of collection of olives, crushing/malaxing with or without water and finally centrifuging/decanting. Variations in the order and the additions of steps exist as can be shown in Figure 1Figure 1, dividing the process, into a traditional (or press) system or continuous (2 phase or 3 phase) system.

FIGURE 1: Olive Oil extraction processes (Azbar N., 2004) (Azbar N., 2004)



There are also the stone removing, percolation, chemical separation and electrophoresis systems as well as the two-phase and a half continuous system. In addition, new emerging techniques have become available on pilot scale including ultrasounds (US), microwaves (MW), and pulsed electric fields (PEF). However, the last four methods are hardly used. Therefore, the following sections present a descriptive summary of the different olive oil extraction systems, from the most used to the least adopted methods.

3.1 TRADITIONAL PRESS SYSTEM

This method is based on extraction by pressure and is the oldest known method. The olives are milled in a stone mill after being cleaned, rinsed, and stored. The remaining material of solid waste can be laid out on disks of filtering material, either fabric or plastic fiber, called pressing mats. The mats are usually piled on top of each other in a wagon and rotated by a central axis. This combination of wagon, mats, and needle axis is called the charge. This charge is pressed by a hydraulic press generated by hydraulic pumps housed in a pump-box. The generated liquid is a combination of olive oil and vegetation water. Natural decantation or settling in tanks is used to separate oil from water followed by a purification stage using a centrifuge. The major advantage of the traditional system is that it incurs the lowest manufacturing cost, short storage time of olive fruit before processing and provides a high-quality oil. However, this system requires high number of staff, and its main disadvantage is that it provides lower oil yield compared to other techniques.

3.2 CONTINUOUS THREE-PHASE SYSTEM

This system was introduced in the 1970s, and replaced traditional pressing with horizontal centrifuges, called "decanters", which considerably improved the performance and productivity of the oil mills. This method presented several advantages over the previous traditional press, by:

• Simplifying mechanical procedures;

• Decreasing labour requirements;

• Allowing continuous production and as such higher olive oil production rate.

This method of continuous extraction requires prior milling, just as the traditional one. After the milling is done with hammers or disks, the remaining paste is sent by pumps of variable speed to a horizontal centrifuge where three phases are separated: the spent olive, also called three-phase spent olives, the oil, and the vegetable water. Spent olives can be further processed as olive-kernel plants to extract the remaining oil and obtain the olive-kernel oil. The consumption of water in this system is notably higher than in other techniques (reported 1.25 to 1.75 times higher than press system) and can reach up to 1,300 liters of water per ton of olives. This is one of the two major disadvantages of this method, the second being the generation of a large amount of vegetable water. This system also requires higher energy consumption and results in the loss of valuable components from the oil, namely antioxidants.

3.3 CONTINUOUS TWO-PHASE SYSTEM

The two main disadvantages of the three-phase system led to the development of the two-phase method, also called the "Ecologic" system. This method produces almost no vegetable water, since it eliminates the addition of hot water to the "decanter". Therefore, it saves water and energy and reduces environmental impact. In addition, its construction is less complex than the three-phase system and the end product is oil of higher quality (with higher antioxidant stability and better organoleptic characteristics).

For the success of this process, modifications in the decanter are necessary to generate two outputs: the first containing oil, and the other containing the majority of solids and constituting water. Therefore, the second component is termed as moist spent olives or two-phase spent olives. This wet pomace is harder to dispose of, as it has higher moisture, sugar and fine solids contents. As such, it is harder to transport, sort and handle. In fact, further cleaning of the oil is required by an energetic process of vertical centrifugation.

3.4 CONTINUOUS TWO-PHASE- AND- A- HALF SYSTEM

This new decanter is realized with a particular design characterized by Variable Dynamic Pressure (VDP), which allows performing real time adjustments of differential speeds between drum and cochlea (Dn) and feed rate. Hence, it can be adapted to the characteristics of the paste input also varying from two-phase to three- phase processing modality, leading to a high working flexibility (Chiavaro, 2014).

The advantages of using such a decanter are (Caponio, Summo, Paradiso, & Pasqualone, 2014):

- A better extraction yield without compromising oil quality;
- Allowing the oil extraction without adding water to the paste;
- Leading to a drier pomace than other decanters, which is easy to carry and process and therefore more appreciated by the pomace oil extraction industries.

The main disadvantages of the two-phase-and-a-half system is mainly its higher cost of installation and maintenance and the need for specially trained staff.

3.5 STONE REMOVING PROCESS

This method relates to the production of olive oil without crushing the stones.

Patent number US4370274 (1983) discloses an apparatus for recovering olive oil from destoned olives. Initially, olives are fed to a pulper that separates the olive stones from the pulp. The pulp is then taken up by an extraction screw that subjects the pulp to an extraction pressure sufficient to withdraw a liquid phase, comprising oil, water, and a minor proportion of olive pulp. The liquid phase is collected in a bin and then sent to a clarifying centrifuge that separates the residual pulp from the liquid phase to obtain a mixture comprising olive oil and vegetation water. A purifying centrifuge then separates the vegetable water and a small proportion of solid matter from the mixture to obtain an olive oil, substantially free of vegetation water that is collected in a tank. According to the inventor, the water can be directly disposed of into a sewer-system (Niaounakis & Halvadakis, 2006).

Additional devices that may be used are disclosed in: IT1276576 and IT1278025. As above, these devices can be used to separate the pulp from the stones prior to processing of the crushed olive pulp into oil, water, and solid residues.

Patent number EP581748 (1994) describes a process comprising the steps of:

1. Kneading the olives in a thermo-regulated room without crushing the stones, obtaining a homogeneous and completely granulated paste at about 40–45 ˚C, because of the combined action of temperature, mechanical stirring, and motion of metallic surfaces within the paste;

2. Extracting the oil by circulation of hot water at about 40–45 ˚C, with a ratio water to paste of 3:1;

3. Filtering the paste by gravity where the separation of water and oil occurs.

Vegetable water produced by the stone-removing process has the following advantages:

• Reduction of the pollution load of vegetable water (due to the removal of the not crushed stones); with respect to those produced by the conventional processes, due to the following features:

• Lower acidity,

• Reduction of BOD5, up to 8 times that of the conventional process,

• Smaller amount of organic compounds refractory to biological digestion,

• Smaller amount of suspended solids.

• Reduction of production and undertaking costs of the mill, as the used machines are considerably cheaper than the conventional ones for what concerns supplying, installation, and maintenance. With the same production, smaller nominal power of the engines is required and this means that the energy demand and undertaking costs are reduced.

• Obtaining oil of high quality as the stones are removed.

• Eliminating the olive stones that absorb a considerable part of the produced oil; the production yield is, therefore, increased.

• Use of the olive stones as an energy resource, in consideration of the fact that the olive stones have a greater calorific value than common firewood;

• Facilitating the easier recovery of ‘‘useful’’ polyphenols such as hydroxytyrosol.

Vegetable water thus obtained is substantially free of compounds that are found primarily in olive stones, such as tyrosol and other highly polluting monophenolic compounds.

The use of new technologies to extract oil from destoned paste can improve the oil phenolic concentration. The phenolic oxidation during processing is catalysed by peroxidase, which is highly concentrated in the olive seed.

The destoning process, by excluding the olive seed before malaxation, partially removes the peroxidase activity and consequently can reduce the enzymatic degradation of the hydrophilic phenols in the oils processing, thus, improving their concentration and oil oxidative stability (Servili M. et al., 2004).

3.6 PERCOLATION

This method, also known as Sinolea, consists of rows of metal discs or plates that are dipped into the olive paste. The oil preferentially wets and sticks to the metal and is removed with scrapers in a continuous process. It’s based on the different surface tension of the vegetable water and the oil, these different physical behaviours allow the olive oil to adhere to a steel plaque while the other two phases stay behind.

Sinolea works by continuously introducing several hundreds of steel plaques into the paste thus extracting the olive oil. This process is not completely efficient leaving a large quantity of oil still in the paste, so the remaining paste has to be processed by industrial decanter. The main advantages of the Sinolea technique are that it operates in continuous, automated cycles which require low labour and the quality of the oil is characterized by good aroma and flavour (Khdair, Ayoub, & Abu-Rumman, 2015). The main drawback of the percolation method is that, it does not provide high oil yields, especially when pomace has a high content of water (Khdair, Ayoub, & Abu-Rumman, 2015).

3.7 CHEMICAL SEPARATION

The working steps of this method consist of the following (Niaounakis & Halvadakis, 2006):

• Crushing the olives by millstones, simultaneously crushing the stones and obtaining the olive paste.

• Dilution of the paste with alkali containing water within suitable tanks equipped with heat steamers.

• Standing within said tanks to separate the oil phase that lasts many hours.

Such a method has been virtually abandoned although it has the merit to have first opened a way to research on which the modern method of centrifugation of paste is based (Niaounakis & Halvadakis, 2006).

3.8 ELECTROPHORESIS

The separation of the oil is obtained by electrophoresis. This method has been developed only at an experimental stage and comprises the following steps:

• Crushing the olives and kneading the paste.

• Diluting the paste by hot water with a ratio 3:1 (water/paste) to obtain a homogeneous mixture.

• Separating the oil by floatation; the mixture of water/paste is subjected to the passage of direct current that by electrophoresis determines the de-emulsification of the oil that is available after a certain time at the head of the electrophoresis tanks.

However, just like the chemical separation technique, in practice, this method has been abandoned (Niaounakis & Halvadakis, 2006).

3.9 NEW EMERGING TECHNIQUES

In recent years, progress has been made in the application of emerging technologies in olive oil extraction. Ultrasounds (US), microwaves (MW), and pulsed electric fields (PEF) have already found application in the olive oil extraction process on pilot scale plants (Clodoveo, 2013).

3.9.1 Ultrasound

Ultrasound (US) is a form of energy generated by sound waves of frequencies above 16 kHz (Jayasooriya et al., 2004).

Two main mechanisms of US could be useful to optimize the olive oil extraction process: the mechanical and the thermal effects (Clodoveo, 2013). Mechanical action is due to the cavitation phenomena (Luque Garcìa & Luque de Castro, 2003) which disrupt the biological cell walls (Cravotto, et al., 2008). Heating occurs as the ultrasonic energy is absorbed in a medium (Jayasooriya et al., 2004; Zheng & Sun, 2006).

The sonication treatment was applied on olive paste after crushing. The malaxing phase can theoretically be divided into two different stages. The first stage, which constitutes around 50% of the total process time, is defined as ‘‘pre-heating’’, i.e. the time required for the olive paste to achieve the process temperature (30°C). The second stage can be defined as the ‘‘effective malaxation’’.

When the US treatment to the olive paste is applied instead of the conventional heating system (Clodoveo et al., 2013 b & c), a quick heating of the product occurs. Applying the conventional heating method to the olive paste, the length of the pre-heating stage is about 45% of the total process time, taking 25 minutes to carry the olive paste up 30°C before the “effective malaxation” stage. With the US treatment (35 kHz – 150 W) of the olive paste (2.5 kg), the pre-heating length is about 10 minutes, corresponding to a 60% reduction in respect to the conventional system.

Parameters legally established (acidity, peroxide value, K232, and K270) to measure the level of quality of the virgin olive oil are not affected by the US treatments. A sensory analysis reveals that the application of a US treatment did not generate any bad flavour or taste in the oil.

The ultrasound technique improves antioxidant content in virgin olive oil, and in Coratina virgin olive oil improves its taste by reducing the bitter and pungent notes, which are not always accepted or desirable by consumers. Ultrasound treatment of olive paste before malaxation increases the process efficiency by reducing the malaxation step, so it represents a useful strategy to reduce the number of malaxers thus reducing the plant costs. Moreover, US treatment significantly improves the extractability of ‘‘Coratina’’ virgin olive oil (Clodoveo 2013 a).

3.9.2 Microwave

MicroWaves (MW) are non-ionizing electromagnetic waves of frequency between 300 MHz to 300 GHz (Banik, 2003).

Applying the MW treatment (800W) on the olive paste (2.5 kg) achieves a pre-heating length of about 3 minutes, corresponding to an 88% reduction in respect to the conventional system. The test does not affect the quality of the olive oils. However, the oils obtained by applying the MW treatment on olive paste are more pigmented than the conventional ones. This is because the MW cause an increase of vegetal tissue volume, disrupting the cells and releasing the pigments. This visual observation has been confirmed by the analytical data (Clodoveo, 2013).

Noting that these compounds act as pre-oxidants in the light, this olive oil should be stored in the dark and in adequate bottles (Malheiro et al., 2013) to preserve its quality and shelf-life. Considering the effect of MW treatment on extraction yields, employing the pilot scale plant, the extraction yield was 16.7

% (± 0.2), and 17.1 % (± 0.1) for the conventional and MW treatment respectively. When the olive oil was extracted without malaxing, the extraction yield of untreated sample was 1.0 % (± 0.1) while the MW treatment produced a significant increase in extraction yields equal to 5.4 % (± 0.3). These results demonstrate that this innovative treatment has a mechanical effect on olive paste causing the rupture of cell walls and recovering the oil trapped in the uncrushed olive tissue (Li et al., 2004; Cravotto et al., 2008). This data opens up new prospects for developing an innovative continuous extraction system to overcome the actual obsolete malaxing batch technology. In fact, a secondary effect should be considered: the crushing step may create an emulsion that impedes the complete separation between the oil and water; the emerging MW technique can facilitate the emulsion phases' separation determining the coalescence phenomena in a shorter time compatible with the development of a continuous system (Nour et al., 2010), (Clodoveo, 2013).

3.9.3 Pulsed Electrical Fields

PEF treatment involves the application of short pulses of high voltage in order to disrupt biological cells in the food material.

The treatment consists of the application of very short electric pulses (1 – 100 s) at electric field intensities in the range of 0.1 – 1 kV/cm (reversible permeabilization for stress induction in plant cells), 0.5 – 3 kV/cm (irreversible permeabilization of plant and animal tissue) and 15 – 40 kV/cm for the irreversible permeabilization of microbial cells. The aforementioned field intensities lead to the formation of a critical transmembrane potential, which is regarded to be the precondition for cell membrane breakdown and electroporation. The irreversible electroporation results in a loss of turgor, the leakage of cytoplasmic content and lysis. Reversible permeabilization leads to the formation of conductive channels across the cell membrane but electrically insulating properties will recover within seconds (Clodoveo, 2013).

Abenoza et al. in 2012 studied the effect of the application of PEF treatments of different intensities (0–2 kV/cm) on Arbequina olive paste in reference to olive oil extraction at different malaxation times (0, 15, and 30 min) and temperatures (15 and 26 °C). They observed that when the olive paste was treated with PEF (2 kV/cm) without malaxation the extraction yield improved by 54 %. At 15 °C, a PEF treatment of 2 kV/cm improved the extraction yield by 14.1 %, which corresponded with an enhancement of 1.7 kg of oil per 100 kg of olive fruits. So, they suggested that the application of a PEF treatment could permit reduction of the malaxation temperature from 26 to 15°C without impairing the extraction yield. Therefore, the treatment of the olive paste with PEF has the potential to induce cell disintegration and to facilitate the release of the small oil droplets. The facilitated release of oil from the cell provides the potential to perform the malaxation at lower temperature with beneficial effects on the oil quality (Kalua et al., 2007). The acidity, peroxide value, K232, and K270 of olive oil were not affected by the PEF treatments like the sensory analysis (Clodoveo, 2013).

Moreover, PEF also has the potential to increase olive oil phytonutrient content and to improve consumer health benefits and olive oil shelf life. PEF treatment also provides energy and time savings – compared to thermal or enzyme treatment – and improves oil quality. These preliminary results stimulated the scaling up of this technology and a commercial product was developed (Clodoveo, 2013).

4. GENERATED WASTES: CHARACTERISTICS AND EMISSION LEVELS

After the detailed listing of the various systems and techniques used in extracting olive oil both on the industrial and laboratory/experimental-pilot scale, this section will focus on the wastes generated by the most widely used systems (pressing, three-phase and two-phase, their by-products). More specifically, the OMWW or vegetable water and the solid waste product that are generated with the pressing system and the three-phase continuous system, as well the slurry waste or wet pomace that is produced in the two-phase olive-mills.

The characteristics of OMWW vary widely depending on many factors starting with the properties of the fruit itself, its cultivation timing and method but most importantly its production method. Generally speaking, however, OMWW have the following common properties:

- Dark colouration (dark-brown/black);
- Olives' particularly strong acidic smell;
- Acidic pH value, varying between 3 and 5.9;
- High solid matter content (up to 20 gL^{-1})
- Low biodegradability, due to its COD/BOD_5 ratio of 2.5 to 5;
- High concentration of phenols (up to 80 gL^{-1});
- High organic content;

Traditional extraction is considered a discontinuous system in comparison to the other two. However, the continuous three-phase extraction system introduced the major disadvantage of producing large quantities of vegetable water. The continuous two–phase extraction system is a variant of the three-phase system, which generates relatively low amounts of vegetable water. TABLE 5 presents the input - output balance of materials and energy in the three different systems presented herein.

TABLE 5: Input-Output Analysis of Materials and Energy in the Three Extraction Systems for the Production of Olive Oil

System	INPUT		OUTPUT	
	Item	Quantity	Item	Quantity
Traditional Extraction	Olive	1 Ton	Oil Spent Olives Vegetable water	200 Kg 400-600 Kg 400-600 Liters
	Rinsing Water	100-200 Liters		
	Energy	40-60 kWh		
Three-phase Extraction	Olive	1 Ton	Oil Spent Olives Vegetable Water	200 Kg 500-600 Kg 1000-1200 Liters
	Rinsing Water	100-120 Liters		
	Additional Water	700-1000 Liters		
	Energy	90-117 kWh		

Two-phase Extraction	Olive	1 Ton	Oil Spent Olives Vegetable water	200 Kg 800 Kg 100-150 Liters
	Rinsing water	100-120 Liters		
	Energy	<90-117 kWh		
Two-and a half phase Extraction	Olive	1 Ton	Oil Spent Olives Vegetable water	200 kg 560-600 Kg 330-350 Liters
	Rinsing water	100- 200 Liters		
	Energy	90-117 kWh		

Source: (RAC/CP, 2000) (Alfa Laval, 2006)

The below tables, Table 6, 7 and 8 (Azbar N., 2004) detail the characteristics of the different types of wastewater and solid waste typically generated from a two-phase, three-phase and traditional press mills respectively.

TABLE 6: Characteristics of Different Types of Wastes from Two-Phase Processes

Parameters	Mixed wastewater -solid waste	Stone-free mixed waste	De-oiled stone-free mixed waster	Mixed waste dried at 400◦C
pH	5.3–5.8	4.87	5.00	5.80
Ash, % wt	7.10–7.46	7.65	9.12	—
Lipids, % wt	4.34	7.18	6.38	12.48
Proteins, % wt	13.56–14.80	9.44	8.65	15.96
Sugars, % wt	1.30–2.31	1.48	1.21	1.87
Tannins, % wt	1.25–2.70	2.18	2.61	1.33
Nitrogen, % wt	2.48–3.16	2.10	1.96	3.08
LHV,* kcal kg^{-1}	27.61	15.04	22.45	—

∗Lower heating value.

TABLE 7: Characteristics of wastewaters from three-phase process

Parameters	Value
pH	3.0-5.9
Chemical oxygen demand (COD), g L^{-1}	40–220
Biochemical oxygen demand (BOD), g L^{-1}	23–100
Total solids (TS), g L^{-1}	1–102.5
Organic total solids (OTS), g L^{-1}	16.7–81.6
Fats, g L^{-1}	1–23
Polyphenols, g L^{-1}	0.002–80
Volatile organic acids, g L^{-1}	0.78–10
Total nitrogen, g L^{-1}	0.3–1.2

TABLE 8: Characteristics of wastewaters from conventional press and three-phase processes

Parameters	Press	Three-phase
pH	4.5-5.0	4.7-5.2
Total solids, %	12	3
Volatile suspended solids, %	10.5	2.6
Mineral suspended solids, %	1.5	0.4
Suspended solids, %	0.1	0.9
Chemical oxygen demand (COD), g L^{-1}	120-130	40
Biochemical oxygen demand (BOD), g L^{-1}	90-100	33
Sugars, %	2-8	1.0
Total Nitrogen, %	5-2	0.28
Polyalcohols, %	1.0-1.5	1.0
Pectin, tannin, %	1	0.37
Polyphenols, %	1.0-2.4	0.5
Oil and grease, %	0.03–10	0.5-2.3

As can be easily deduced from the above tables, all biochemical and physical qualities of OMW vary widely between different processes and as such, any proposed treatment should take into account the above variations along with the quantity and available budget.

In the following chapter, we present the elements based on which Best Available Techniques (BAT) were chosen and we elaborate on suggested existing BAT, the whys and the hows, including emerging techniques and technologies.

5. TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

5.1 INTRODUCTION

Although the present document is intended for use in the SWIM-H2020 SM Partner Countries (non-EU), it has been requested within the specific work package, to present the state-of-the-art techniques related to the minimisation of the olive oil production environmental footprint. This is directly linked to the determination of the Best Available Techniques on which there is considerable experience, work and legal frameworks developed within the EU.

As per the IPPC Directive 2010/75/EU (on Industrial Emissions- Integrated Pollution Prevention and Control) 'best available techniques' or BAT means the most effective and advanced stage in the development of activities and their methods of operation; which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and their impact on the environment as a whole:

(a) 'techniques' include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

(b) 'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the country in question, as long as they are reasonably accessible to the operator;

(c) 'Best' means most effective in achieving a high general level of protection of the environment as a whole;

This chapter presents techniques that are generally considered to have potential for achieving a high level of environmental protection in the olive oil production sector. It covers environmental management systems, process-integrated techniques and end-of-pipe measures. Waste prevention and management, including waste minimisation and recycling procedures are also considered. Furthermore, techniques for reducing the consumption of raw materials, water and energy and for valorization of by-products are covered. All in all, prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Annex III of the Directive 2010/75/EU lists a number of general considerations to be taken into account when determining BAT, and techniques within this chapter will address one or more of these considerations. A standard structure has been used to outline each technique (as shown in TABLE 9), enabling comparison of techniques and facilitating objective assessment against the definition of BAT given in the Directive.

It is important to mention here that the content of this chapter is not an exhaustive list of available techniques and others may exist or be developed which may be equally valid within the framework of BAT.

TABLE 9: Information about techniques for consideration in the determination of BAT

Type of information considered	Type of information included
Description/parameter	Technical description of the technique
Environmental impacts	Main environmental impact(s) on soil, water and air to include noise and public health elements, as well as cross-media effects. Environmental benefits of the technique in comparison with others
Operational data (human resources and physical facilities)	Performance data on emissions/wastes and consumption (raw materials, water and energy). Any other useful information on how to operate, maintain and control the technique, including safety aspects and operability constraints of the technique, output, quality, etc.
Applicability	Consideration of the factors involved in applying and retrofitting the technique (e.g. space availability, process specificity, scale [pilot versus commercial])
Economics and financial resources	Information on costs (investment and operation) and any possible savings (e.g. reduced raw material consumption, waste charges)
Driving source for implementation	Reasons for implementation of the technique (e.g. other legislation, improvement in product quality)

5.2 OLIVE OIL EXTRACTION TECHNIQUE SELECTION

Olive oil extraction techniques have been elaborately described in Chapter 2. As mentioned previously, the choice of the extraction technique depends on many factors including extraction efficiency (oil yield), quality of the olive oil produced, processing time, equipment prices, water and energy consumption, existing infrastructure for the management of by-products and legal framework.

Generally speaking, olive oil production consists of two main stages: the preparation of a homogeneous paste and the oil extraction from the olives (Salomone, et al., 2015).

Traditional pressing (a discontinuous process) is still in use in some small mills that use a hydraulic press, allowing lower manufacturing costs, better oil quality and shorter storage time of olives before processing. This process generates a solid fraction (olive pomace) and an emulsion containing the olive oil, which is separated by decantation from the remaining vegetable water.

In the three-phase system, olives are washed then milled and beaten. They are then subjected to horizontal centrifugation, when a considerable amount of hot water is used for facilitating extraction. The separation of the solid residue (olive pulp and stones known as olive cake, which constitutes around 30% of residues) happens then in the decanter. This leaves the aqueous residues to be treated in the vertical centrifugation, where olive oil (around 20% of the yield) is separated from the OMWW (the remaining 50% of yield composed of water content of the fruit and process water, as well as the water used to wash the olives). The advantages of such a system is that it requires less human labour and delivers a higher olive oil production rates compared to the traditional pressing system. However, it has other disadvantages, such as greater water and energy consumption as well as the loss of valuable components of oil (namely its natural antioxidants) and creates the problem of disposal of an increased volume of OMWW.

What is currently considered as a best available technology is the shift to the continuous two-phase centrifugation system. This system allows the separation of oil from olive paste without the addition of water and this leads to the elimination of the vegetable water phase. The process starts with washing the fruit, milling and beating and then horizontal centrifugation without the addition of water resulting in a semi-solid waste called olive wet pomace and a liquid phase, followed by oil washing and vertical centrifugation which results in waste water and olive oil. The advantage of the two-phase compared to three-phase is that the construction of two-phase is less complex and proved more reliable and less expensive in the decanting phase. It uses considerably less water and energy and the oil produced is of higher quality with higher oxidation stability and better organoleptic characteristics.

On the other hand, there are disadvantages to this system. To start with, the semi solid waste is not easy to properly dispose of and the composting of the wet pomace is difficult as it has higher moisture content (of 55-70%), sugar and fine solids then its equivalent in the three-phase system. In addition, the pomace constitution makes it hard to transport, store and handle. Finally, residues are more concentrated in fats, dry residues and phenols and have higher COD and turbidity. Hence, the move towards a continuous centrifugation with a two-and-a-half-phase system (also called a modified system or water-saving system). This system lies between a three-phase system and a two-phase one, bringing together the advantages of the two different systems. It requires the addition of a small amount of water and generates olive wet pomace that includes part of the vegetable water and a smaller quantity of OMWW (Salomone, et al., 2015).

Another technology involved in oil extraction is the de-stoning of olives. The pits of the olives are removed before malaxation and kneading, while some authors contend that de-stoning produces better oil quality (Pattara et al 2010), others state that this technique leads to lower yields (diGiovacchino 2010). Nonetheless, de-stoning is only a preliminary technique and not an extraction method as the olives have to be subsequently treated either in a three-phase or two-phase or two and half phase systems.

In the below section, we start discussing the two-phase system as it is still considered the best available technique in the market. Then we move on to the remaining industrially based ones and finish by describing and analysing the various management techniques used for the treatment and valorisation of its by-products, especially as every technique delivers different wastes, varying in physicochemical and biological profiles as well as in volume and quantity.

5.2.1 Two-Phase System

5.2.1.1 Description

As described above, the continuous centrifugation with a two-phase system allows the separation of oil from olive paste without the addition of water and this leads to the elimination of the vegetable water phase generating only olive oil and olive wet pomace.

5.2.1.2 Environmental impacts and cross media-effect

The continuous centrifugation with a two-phase system saves process water by 80% and energy by 20% (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004).

The greenhouse gas intensity of olive oil produced in two-phase extraction is 9% lower than that of three-phase extraction (mainly due to higher emissions in wastewater treatment extraction in three phases) (Figueiredo, Marques, Castanheira, Kulay, & Freire, 2014).

The throughput of the two-phase centrifuge, related to the oil quantity, is higher because no additional water is required to produce the pulp (Niaounakis & Halvadakis, 2006).

The two-phase process, although it produces no wastewater as such, combines the wastewater that is generated with the solid waste to produce a single effluent stream of semi-solid form (30% by mass). This double the amount of ‘‘solid’’ waste or wet pomace requiring disposal, and it cannot be composted or burned without some form of (expensive) pre-treatment (Niaounakis & Halvadakis, 2006).

The wet pomace has a moisture content of 55–70%, while the traditional olive cake or pomace has a moisture content of 20–25% and 40–45% in the press system and the continuous three-phase centrifugation system, respectively. This greater moisture, together with the sugars and fine solids that in the three-phase system were contained in the olive mill wastewater give the wet pomace a doughy consistency and makes transport, storage and handling very difficult. It cannot be piled and must be kept in large ponds (Niaounakis & Halvadakis, 2006).

The wet pomace is characterized by higher values of the pulp/stone ratio, as well as greater weight produced. The effluent is therefore more concentrated and thus richer in fat, dry residue, phenols, and o-diphenols. The COD and turbidity values of this residue are higher than that of the traditional and three-phase systems (Niaounakis & Halvadakis, 2006).

The two-phase technology transfers the problem of disposing of the olive-mill waste from the mill to the seed-oil refineries; the wet pomace, prior to oil solvent extraction, must be dried with considerably higher energy requirements than in the case of traditional or continuous oil production processes, making the industrial recovery of the residual oil difficult and expensive (Niaounakis & Halvadakis, 2006).

The continuous two-phase centrifugation technique also endangers solid waste de-oiling facilities operating as recovery units (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004).

5.2.1.3 Operational data

Continuous centrifugation with a two-phase system consumes low to no quantities of water compared to other techniques. In addition, the construction, operation and maintenance of a two-phase system is less complex than a three-phase system and decanters in a two-phase system have proved more reliable and less expensive than its three-phase competitor. The human resources required are the same as the three-phase system but significantly less than that required in the traditional press system. However, it has a reduced capacity of 20-25% compared to the three-phase system. It is as well less stable with difficult yield control.

5.2.1.4 Applicability

In 1992, the two-phase extraction system was introduced in the region of Andalusia. Nowadays, almost all olive-mills in Spain use two-phase centrifugal decanters (Niaounakis & Halvadakis, 2006) (Alvares de la Puente, 2010). The continuous centrifugation with a two-phase system is applied almost in all olive oil producing countries.

The two-phase technology was supported by national policies in Spain aimed at minimizing the high costs of wastewater handling and disposal. The system has benefited from public funding for implementation. Some of the small olive oil enterprises resist switching to the two-phase process, especially if water economy is not a major consideration. Some manufacturers claim that water addition is always necessary to meet the required traditional olive oil quality. Still another case is that of premises equipped with already existing three-phase centrifugation capacity. For these reasons, switching into two-phase from three-phase technology has been difficult, and some producers prefer to continue using the three-phase process. A permitted two-phase plant may easily be operated as a three-phase plant (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004).

With the two-phase system, the problem was transferred from the olive mills to the pomace processing plants. The wet pomace cannot be sold by olive mills to pomace plants which reduced their income and this wet pomace which is a popular biomass for home heating in certain countries like Syria and Lebanon could not be used anymore.

A system was developed by Pieralisi under the name of Leopard which consists of a two-phase decanter apparently producing a dehydrated husk/pomace similar to that of three-phase. It is proposed by Pieralisi as recovering a wet pulp directly inside the bowl, ideal for uses such as composting or animal feeding, turning a by-product to be disposed of into added value. Leopard is advertised as combining the advantages of modern extraction technology without the addition of water (two-phase) with the versatility of a decanter able to run both in continuous and in-batch processing (Gruppo Pieralisi, 2019) (OliveBiz, 2012). This system aims to solve the problem of wet pomace that is hard to handle in some countries.

5.2.1.5 Economics and financial resources

The two-phase technology saves process water by 80%, and energy by up to 20%. It requires less investment cost by as much as 25% compared to the three-phase system (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004). When buying a new olive oil mill, the cost for the three or two phase technology is almost the same. However, shifting from 3- phase to 2- phase there is a need to buy a new decanter which costs around 50,000 to 60,000 EUROS for a capacity of 1.5 tons / hour (Fares, 2019). Some decanters can be converted from 3-phase to 2-phase for 6,260 to 8,760 Euros as per the Jordanian experience (Mheisen, 2019). Therefore, some challenges for shifting to the 2-phase system include the cost of changing some equipment, the need to equip the mill with appropriate areas to store the wet pomace, and drying the wet pomace to use it as a source of energy becomes harder (Mheisen, 2019). Noting that the 3-phase system is older and has been applied for long time, mill owners are usually more familiar with it and it is easier for them to operate and maintain. It is also considered that the production is fastest using the 3-phase system (Mheisen, 2019).

5.2.1.6 Driving force for implementation

The driving force for using the two-phase system is water and energy savings as well as the prevention of the generation of OMWW which has high polluting potential if not properly managed. The system improves oil quality and preserves antioxidants in the oil.

5.2.1.7 Case Study: Switch to two-phase system in Andalucia

As presented by Alvares de la Puente, J. in 2012, Andalucia has opted to switch to the two-phase system by 2013. In addition, the switch to two-phase system was accompanied with a call to couple it with composting to avoid the system's major disadvantage, which is the cumbersome produced wet pomace. The choice for composting settled on the aerated static piles system. It was found in the Andalusian case that the cost for chemical compost comes up to 1.9 Euro/tree compared with 0.65 Euro two-phase compost. This has further consolidated the decision for the switch to two-phase (Sousa, 2012) (Puente, 2012).

Composting initiatives have been supported by the Andalusian agricultural and environmental administrations, which since 2002 provided technical assistance in promoting and monitoring of these actions. It also provided financial support by subsidies from European funds FEADER until 2013, to build recycling plants. The aid was aimed at the mills for their wet pomace composting, but from 2009 was extended to any agribusiness to produce compost from their organic products (Sousa, 2012).

In lands owned by the mills, the wet pomace is composted in small or medium-sized plants, with a waterproof surface, usually concrete (as required from the Ministry of Environment to prevent contamination of soils and aquifers). The residue is mixed with the cleaning sheet of the olive, to give structure, and add manure to improve their nitrogen content. Typically, the simplest composting system used is the open, aerated by turnings with loader. Once composted, the usual fate of the compost is to incorporate it into the olive groves (Sousa, 2012).

5.2.1.8 Case Study: Morocco Oued Jdida Meknes two-phase mills

“La societé de OLEA FOOD” study in 2017 focuses on the location of the Oued Jdida Meknes area in Morocco for a future two-phase system operation that includes thermal treatment (drying) of OMW (pomace) facilities (SWIM, H2020, 2017).

After considerations of various factors, the study concluded, in line with available literature that the two-phase system will result in an average of 70% water saving, cleaner (10 times less charged) effluent water than that produced in a three-phase system and a high quality of oil. However, they also realized that the problem of treatment is transferred to the wet pomace which requires energy to dry which could cost up to 300,000 euros for the Meknes area.

Meknes is some 23 Km from Fes in the north of Morocco and the site project proposed for the two-phase mill and the treatment of produced pomace will be in the rural area of Oued Jdida on a 2,000 m radius surface area. The project is hopeful to construct an olive oil mill with a capacity of 450 t/day and treating wet pomace units with a capacity of 1,560 t/day. The pomace drying units will be composed of rotary dryers with 12,0000,000 Kcal/hr calorific power. A de-stoning unit is to be provided of a 1,600 t/day capacity. Stainless steel containers of 2,000 t capacity are planned for the storing of the olive oil.

Energy provision will be ensured via three electrical posts of 630 KVA each and linking to the local public network which is at 300 m away from the site.

Water provision will be ensured by linking to the local public network which is at 10 m from the site, as well as the creation of one well on site for sanitary and cleaning water supply.

A total of 224 m^2 building area will be provided to host personnel. Various separate locations of various appropriate surfaces will be constructed for oil production, storage of seeds, pomace, vegetable water and oil, and for drying/treatment of pomace.

Construction of platforms to collect olives will be done, as well as basins to receive wet pomace (volume 9,720 m^3), de-seeded wet pomace (volume 14,625 m^3) and to prepare pomace for treatment (volume 600 m^3), as well as 4 evaporation ponds (lined reinforced concrete with a geomembrane, total volume 7,350 m^3) and borehole or septic tank (volume 75 m^3).

Olives are to be transported in closed trucks with a carrying capacity of 450 t/day, whereas the pomace will be carried in tank trucks that can accommodate 1,560 t/day.

Total water consumption (100 days of work) is predicted to be at 10,383 m^3 and energy to amount for 921,000 KW.

The expected effluents per season are 8,325 t of oil and 2,340 t of oil after secondary treatment destined to be stored and bottled for local and international sales.

The liquid effluents will be that of the washing waters amounting to 5,025 m^3 and these are destined for the evaporation ponds. Vegetable water will be directly used as soil enricher. Wet pomace totalling 135,593 t will be destined for drying. Leaves amounting to 1,575 t and 23,400 t of seeds will be valorized as energy source back into the operation. Seeds as well as dried pomace are expected to contribute with 7.2 KWh/Kg) in calorific power or the equivalent of 15 million Liters of fuel. In addition, this contribution assists in lowering CO_2 emissions by around 45,000 t.

The cost of the project is estimated to be around 400,000 euros, of which 38% is to be allocated for the treatment of OMW. The project is estimated to create around 100 new jobs. In terms of environmental impact, there is no direct negative impact as there will be no liquid waste and as such, lower COD contamination of the water table by around 15,600 t or the equivalent of pollution by 350,000 inhabitants/year. Air and noise pollution is expected to be minimal. On fauna and flora, the impact is expected to be negligible.

5.2.2 Three-Phase System

5.2.2.1 Description

As described previously, the continuous centrifugation with a three-phase system allows the separation of oil from olive paste with the addition of hot water which leads to the formation of three phases: olive oil, vegetable water and pomace.

5.2.2.2 Environmental impacts and cross media-effect

The main advantage of the three-phase process over the two-phase is that the produced wastewater and pomace are easier to handle, store and dispose of than its counterpart wet pomace produced in the two-phase system. In fact, pomace has a moisture content of 40–45% compared to 50-70% in the two-phase technology. Pomace of the three-phase system has lower fat, dry residue, phenols, and o-diphenols than the wet-pomace. The COD and turbidity values of this residue are lower as well (Niaounakis & Halvadakis, 2006).

However, the three-phase system consumes water by 80% and energy by 20% more than in the two-phase system (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004). As such, the greenhouse gas intensity of olive oil produced is 9% higher than that of two-phase extraction, mainly due to higher emissions in wastewater treatment extraction (Figueiredo, Marques, Castanheira, Kulay, & Freire, 2014).

The three-phase technology's main problem of high consumption of water and energy can be partly addressed if proper measures are taken into recycling water and energy into the system, especially if combining production with waste management via thermal and/or biological treatments to produce biomass and fertilizers. Its second major problem is the volume of produced water vegetable. This however, as previously mentioned, can become an asset if by-products are properly re-used including for irrigation.

5.2.2.3 Operational data

Similar to the two-phase system, the three-phase system requires less labour/human resources and has proven more reliable than the traditional press system. It has proved to be more flexible, stable and has larger capacity than the two-phase system. In addition, it has delivered better olive oil yield than the traditional press system. In case of financial capabilities, the system is easy to acquire, install, operate and maintain (Alfalaval 2003).

5.2.2.4 Applicability

The continuous centrifugation with a three-phase system is applied almost in all olive oil producing countries. The three-phase technology was the first to be applied instead of the traditional press system, decreasing labour cost dramatically, as well as achieving a much higher yield and more reliable process. In areas where water economy is not of major consideration, olive oil manufacturers were happy to switch from the traditional to the three-phase system. In fact, as previously stated, some manufacturers prefer the three-phase to the two-phase system because they believe water addition is always necessary to meet the required traditional olive oil quality. (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004).

5.2.2.5 Economics and financial resources

Economically speaking, and on the medium to long term basis, switching from the traditional to the three-phase system makes sense as the improvement in the yearly yield and quality of olive oil adjusts for the capital cost. In addition, there has been an abundance of governmental and institutional financial support and assistance for manufacturers to switch to three phase system from the 1970s onwards (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004).

5.2.2.6 Driving force for implementation

The driving force for using the three-phase system has been the mechanization (and as such productivity and hygienic standardization) as well as yield improvement over traditional pressing. In areas where water consumption is not an issue, three-phase system remains the preferred technology.

5.2.3 Two-Phase-and-a-Half System

5.2.3.1 Description

As described previously, the two-phase and a half system is realized via the Variable Dynamic Pressure (VDP) of the decanter, which means that real time adjustments of differential speeds between drum, cochlea and feed rate can be done. In practical terms, this translates into high working flexibility (Chiavaro, 2014).

5.2.3.2 Environmental impacts and cross media-effect

The main advantage of this system over the two and three phase systems and traditional pressing, is that it provides better extraction yield without compromising the oil quality and without resorting to addition of water to the paste. This means that the pomace produced is drier than the wet pomace of the two-phase system and slightly wetter than the pomace of the three-phase system. Such pomace is easy to store, handle, treat and transport (Caponio et al, 2014).

5.2.3.3 Operational data

This system's main disadvantage is in its operational facility as, despite being available and reliable, it requires special training for the installation, operation and maintenance of the system. This requires specially trained staff to install operate, maintain and clean the machines, which adds time and cost to its operation.

5.2.3.4 Applicability

Capital costs as well as appropriate staffing remain the two major obstacles facing the applicability of the two-phase and a-half system.

5.2.3.5 Economics and financial resources

Economically speaking, on the long-term basis, switching to two-phase-and-a-half system makes sense as the improvement in the yearly yield and quality of olive oil adjusts for the capital cost. In addition, the by-products are easier to handle (store and transport) and treat and provides a good source for biomass and fertilizers when properly treated.

5.2.3.6 Driving force for implementation

The driving force for using this system has been to adjust the difficulty presented by the two-phase system's wet pomace. As the name conveys, it plays center stage between the two-phase and the three-phase system, combining the advantages of both.

5.2.4 De-stoning Technique

5.2.4.1 Description

As the name suggests, the de-stoning process refers to the production of olive oil without crushing the stones of the fruit. As explained in chapter 2, there are different patents for devices that separate the pulp from the stone before the former is crushed into oil, vegetable water and pomace/olive cake.

5.2.4.2 Environmental impacts and cross media-effect

The main advantage of de-stoning prior to extraction is that the produced vegetable water has a significantly reduced pollution load. In fact, the vegetable water is less acidic, lower BOD level, and smaller amount of organic compounds and suspended solids as compared to the traditional and continuous processes. In addition, the vegetable waters are free of highly polluting compounds that are found in the stones (tyrosol and other mono-phenolic compounds). The stones can be easily used as an energy source due to their high calorific properties.

5.2.4.3 Operational data

Operational faculty of the de-stoning technique is, of course, dependent on which device has been adopted for the process. However, generally speaking, the machines are considerably cheaper than the conventional ones in terms of supply, installation and maintenance. In addition, the energy requirements and undertaking cost are reduced as well especially as smaller nominal engine powers are required.

5.2.4.4 Applicability

With lower operational costs (than the continuous and traditional systems) and lower pollution load, de-stoning presents a very applicable option as an additional step for oil extraction and the management of polluting by-products.

5.2.4.5 Economics and financial resources

Economically speaking, de-stoning presents a reduction in both production and undertaking costs of the mill. Capital cost is low and machines used are easy to install and maintain. In addition, the process requires small engine power and as such is not high energy consuming. In addition, produced vegetable waters are less polluting and therefore can be more readily stored, transported and/or treated/used. The leftover stones also form a source of revenue income as they can be used to produce heat because of their high calorific value. In addition, because the olives are de-stoned before malaxation, oil yield and quality of oil are improved.

5.2.4.6 Driving force for implementation

Improving oil yield and quality, reducing energy consumption and pollution load of the generated wastes, coupled with lower production and undertaking costs makes of de-stoning an attractive option to implement.

As elaborated in Chapter 2 and the above sections, each process results in a different set of by-products and wastes (see TABLE 10 below). The physicochemical and biological nature and volume of the by-products are determined not only by the extraction techniques, but also by the nature of the olive fruit itself, the harvest method and timing, the storage and handling approach among other factors. Understandably, it ensures that different management processes are required to deal with each type and volume of each by-product. In the following section, each management technique is discussed according to the above-mentioned criteria, starting with the most commonly used to the least applied or laboratory/pilot based ones. The wastes discussed below will be divided into solid wastes or pomace and liquid wastes or vegetable water.

TABLE 10: By-products by different oil extraction systems

	Water Consumption (%)	Pomace (kg/100 kg olive)	Pomace humidity (%)	OMW (kg/100 kg olive)
Three-phase	50	55-57	48-54	80-110
Two-phase	0-10	75-80	58-62	8-10
Two-and-a-half phase	10-20	55-60	50-52	33-35

Source: (Amirante P., 2002)

5.3 TECHNIQUES FOR THE MANAGEMENT OF POMACE

5.3.1 Thermal processes

5.3.1.1 Drying

5.3.1.1.1 Description

For the drying of pomace, many drying processes can be used including contact, convection and radiation drying. In all processes, the pomace is dried via a source of energy/heat and the resulting solid residue is treated with an organic solvent. The most widely used process is convection drying where heat is transferred to the pomace by means of hot gases. Water contained in the pomace evaporates and is conveyed by the hot gas flow (Niaounakis & Halvadakis, 2006). Examples of this type of driers are drum driers and fluidized bed driers. The resulting dried pomace is de-oiled with an organic solvent (hexane) and then, can be either incinerated for energy production, used in agriculture, or landfilled (Niaounakis & Halvadakis, 2006).

A qualitative description of the two-phase wet pomace drying process was developed that describes the characteristics of the different phases that make up the whole process (Arjona, Garcı´a, & Ollero Castro, 1999). The drying process was studied at laboratory scale and the drying rate was determined with respect to operating conditions (temperature and air velocity) and agglomerate size. The operating conditions — size, temperature, and moisture content — at which two-phase wet pomace could ignite and cause a fire in an industrial drier were determined. The loss of volatile matter during the drying process, which modifies the composition of product and may affect the quality of the oil to be extracted, was also evaluated. The results of this experimental work allowed the development of a useful drying model for designing new driers and for assessing the behaviour of existing ones (Niaounakis & Halvadakis, 2006).

The most common solution adopted by the industry is to use two rotary driers in line. The first drier is fed with a mixture of fresh and dried two-phase wet pomace having a moisture content of approximately 52–55% (wet basis) to avoid stickiness and dries it up to 25–30%. The second drier brings the moisture content of the mixture below 8%. Currently, the driers are operated manually or, at the most, with a simple system to control the inlet gas temperature. Arjona et al. developed, implemented, and tested at a 2-phase wet pomace industrial drier with a control system based on PID controllers (applied to the first drier) that minimize the operational problems and improve the production and the energetic efficiency (Arjona, Ollero Castro, & Vidal, 2005).

In the section below, the main advantages of this technique are presented.

5.3.1.1.2 Environmental impacts and cross-media effects

Drying of the olive pomace leads to easier storage and transport conditions, if and when needed. The further treatment with the organic solvent allows the residue to be used for energy production, reused as a fertilizer or if all fails, to be safely disposed of in landfills. It is important to note here that the moisture content of the waste has to reach 5-8% (from 55-70%) in order to be able to extract the residual oil and recover their energy content (Niaounakis & Halvadakis, 2006). This way, the waste has been valorized and its negative environmental impacts majorly reduced.

However, there is always a downside to this technique when compared to other possible ones. The main disadvantage is the high energy demand needed for the drying process to achieve the desired low moisture content of 5-8%. However, this drawback is justifiable against the background that the resulting final product can be reused for generation of energy (Niaounakis & Halvadakis, 2006).

In addition, the drying of two-phase wet pomace presents further challenges because of its high moisture and sugar contents that affect the agglomeration of the pomace. The classical driers, e.g. rotary kilns (drums) and trays, have a low thermal efficiency due to the poor air–solid contact and can present several problems. These dryers were originally designed for three-phase pomace made up of loose particles of stone and pulp with a homogeneous moisture distribution that can be easily piled up and fed through rotary driers. In addition, the high moisture content of two-phase wet pomace (55–70%) demands much more energy (than the three-phase pomace) and the sugars present in it make it sticky and difficult to dry. Two-phase wet pomace tends to stick to the drier's walls, particularly to the initial part of the drum where the gases are hot, obstructing the gas stream and increasing fire risk (Arjona R. et al., 1999) (Niaounakis & Halvadakis, 2006). Two rotary driers can be used to avoid this obstacle. Moreover, drying of wet pomace produces air emissions that must be treated appropriately.

These challenges need to be addressed in order to make thermal treatment of wet pomace a viable option throughout.

5.3.1.1.3 Operational data

The addition of a heating process requires the purchase, operation and maintenance of the heating drums resulting in more cost from a staffing and physical facility perspective. It also results in much higher energy consumption. This all adds up to the air pollution management bill as well.

5.3.1.1.4 Applicability

Despite the investigations undertaken to optimize the drying process of two-phase wet pomace from an operational and energy-saving point of view, the high energy cost of reducing its moisture content remains a clear drawback.

5.3.1.1.5 Economics and financial resources

From an economic point of view, high investment and operating costs and skilled personnel are required for well-functioning drying plants (Niaounakis & Halvadakis, 2006). These, as mentioned above, remain obvious obstacles in the implementation of the thermal drying techniques for the management of the pomace.

5.3.1.1.6 Driving force for implementation

The clear environmental benefits remain the main attraction to implement the two-phase system. In Spain, there has been a major surge in shifting from traditional to two-phase systems accompanied by governmental financial and technical support. Countries such as Italy, Tunisia and Turkey are following suit. However, existing three-phase mills and mills (mostly traditional) with abundant water supplies are still resisting the change (Niaounakis & Halvadakis, 2006).

5.3.1.1.7 Case study: Drying center for Two-Phase pomace by cogeneration and generation from Biomass – The “SEDEBISA”, Andalucia, Spain

The SEDEBISA complex is dedicated to sustainable recovery of between 150,000 and 200,000 tonnes of two- phase wet pomace using a natural gas turbine cogeneration process for drying, the continuous extraction of olive oil and power generation (Sousa, 2012).

The project budget was 46 million euros and the duration of construction extended to 18 months. The plant, occupies an area of 16 hectares, and has been supported by the EU and the Junta de Andalucía through the FEDER and FEOGA (Sousa, 2012).

The cogeneration plant is equipped with a combined cycle gas turbine of 13 MW, a recovery boiler and a steam turbine of 4.4 MW. The combustion gases of the gas turbine are used in the drying of the wet pomace. This technology, compared with traditional drying prevents the formation of benzopyrene in the oil produced (Sousa, 2012).

It also operates an energy recovery plant from biomass, and specifically the use of “orujillo” (residue from oil extraction process of wet pomace), pruning of olive trees and other biomass available in the environment. This plant is composed of a biomass boiler and a steam turbine of 9.8 MW (Sousa, 2012).

The cogeneration facility produces no fumes, odors, mists or dusts in suspension. It works with a sulfur-free fuel, so the only contaminants present in the gases are nitrogen oxides in various forms (NOx) and some carbon monoxide (CO) (apart from CO_2) (Sousa, 2012).

5.3.1.2 Combustion

5.3.1.2.1 Description

Generally speaking, combustion of biomass is applied to convert biofuel to heat. Secondary technologies can also achieve production of other forms of energy from the combustion of biomass (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004). In a simplified term, combustion is the burning of fuel in excess air resulting in heat production. From the biomass, combustible vapors become volatile and then burn as flames (Fokaides, 2013).

This degradation occurs in three fractions (Bridgewater, 2003):

1. Gaseous layer containing CO, CO_2, H_2 and Hydrocarbons
2. Condensable fraction made of water and organic, but low molecular weight sugar residues
3. Tar, made of furan derivatives, phenolic compounds and sugar compounds of higher molecular weight.

It is very common to burn exhausted olive cake to produce heat, mostly to cover the drying energy needs for fresh raw materials.

Co-combustion is also widely used and refers to the addition of supplementary fuel to the main one and the simultaneous firing of both in the same chamber. What co-combustion presents is an advantage in the disposal of waste products and a reduction in fuel cost (Li, et al., 2015).

5.3.1.2.2 Environmental impacts and cross-media effects

In addition to the benefit of avoiding harmful wastes being landfilled without treatment, the produced energy is recycled into the system, avoiding further cost and additional air pollution load. In addition, power production can also be obtained by resorting to secondary conversion technologies (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004) and (Fokaides, 2013).

Compared to other techniques used to treat OMW, combustion of the biomass is a widely used technique because it recycles heat energy within the system. The main disadvantage of co-combustion, although widely used as well, is that because the combustion properties of biomass are very different from those of, say, coals, the biomass substitution ratios becomes very limiting and as such creates complications in the operation of the system (Li, et al., 2015).

5.3.1.2.3 Operational data

Human and technical resources, as well as physical space, are, in general, widely available and easy to attain, making combustion as widely used an option as it currently is.

5.3.1.2.4 Applicability

From the above sections, it is easy to deduce that burning of biomass for heat purposes is a very appealing and easy to implement option, cutting the fuel cost and recycling the overall energy input and output within the system, hence making it one of the most applied techniques in the management of OMW.

5.3.1.2.5 Economics and financial resources

Because of its operational applicability as well as the reduction of the energy bill and valorization of the biomass product, the combustion of olive cake presents an economically viable and, as previously explained, widely used technique.

5.3.1.2.6 Driving force for implementation

The easiness, both from a financial and staffing points of view, as well as the production of a valorized by-product that can be recycled to reduce the energy bill have been the main drives behind the appeal of the combustion and co-combustion techniques.

5.3.1.3 Pyrolysis

5.3.1.3.1 Description

Pyrolysis is a thermochemical method used to convert a biomass to liquid, solid and gaseous fractions by heating the biomass in the absence of air. There is slow, fast and flash pyrolysis and this is according to the applied operating conditions of temperature and rate of heating (Fokaides, 2013). As the names indicate, slow pyrolysis requires low temperature and heating rates, as such, the vapor residence time is high, varying between 5 minutes to half an hour, leading to char production. In contrast, flash and fast pyrolysis lead to higher production of gases since the heating rates and temperatures used are relatively high. The difference between fast and flash is that in the former, a short vapor residence time is applied, whereas the latter is characterized by a very short gas residence (less than 1 second). As expected, different pyrolysis methods lead to different product yields and of the three types, the fast pyrolysis has proved the most popular in the research circle (Meier, 2013), (Chrisoforou, 2016).

5.3.1.3.2 Environmental impacts and cross-media effects

In addition to the benefit of avoiding harmful wastes being landfilled, the produced oil from pyrolysis, especially that of the fast method, is used as fuel oil in burners, engines and boilers to produce electricity or refineries' feedstock (Fokaides, 2013), (Chrisoforou, 2016).

Compared to other techniques used to treat OMW, pyrolysis tends to be expensive and sophisticated and requires capital investment, close monitoring and regular maintenance by skilled labour. In addition, it requires high energy consumption to provide for the high temperature and heating. However, these can be overcome by recycling energy within the system (Meier, 2013).

5.3.1.3.3 Operational data (human resources and physical facilities)

As mentioned above, it is the operational cost and sophistication of pyrolysis that tend to be the main obstacle for its widespread adoption. However, with appropriate training and financial support, these obstacles can be surpassed.

5.3.1.3.4 Applicability

In the absence of proper financial resources and the technical knowledge, pyrolysis does not present an easy option to adopt. Therefore, it has not been a widely applicable technique in the treatment of biomass, especially among small and medium sized mills.

5.3.1.3.5 Economics and financial resources

As can be noted from the above, from an economic point of view, pyrolysis is not (yet) an easily adopted technique as it requires high cost and proper training and financial support. As such, it has remained an option for only the big and wealthy olive mill operators.

5.3.1.3.6 Driving force for implementation

The environmental benefit of recycling harmful waste into fuel constitutes the main driving source for adoption of pyrolysis. The end product can be used as fuel oil or as refineries' feedstock and the high energy consumption can be overcome by recycling energy into the system, offsetting therefore its major drawback.

5.3.2 Biological treatment

Both aerobic (composting) and anaerobic (fermentation) processes can be used.

For composting, bulking material, such as wood shavings, straw, cotton-waste, poplar sawdust, and bark chips, has to be added to achieve proper moisture level and good aeration of the pulp. Unlike wastewater, the wet olive pomace is added at once at the beginning of the composting process. Insignificant consumption of energy and resources are needed, while gaseous emissions are very low (Galanakis, 2017).

The physical characteristics of wet olive pomace causes difficulties during composting by forced aeration systems, therefore mechanical turning is often preferred (Galanakis, 2017).

As far as the fermentation process is concerned, energy and space requirements are very low, while biogas production enables energy recovery. Compared to composting, problems often arise in process control and maintenance, hence qualified personnel is required. Moreover, this technology is affected by higher investment costs (Galanakis, 2017).

The toxicity of phenolic compounds present in wet olive pomace affects anaerobic digestion. Due to its semi-solid state, pomace needs to be mixed with bulking agents, before fermentation (Galanakis, 2017).

5.3.2.1 Composting of pomace

5.3.2.1.1 Description

Aerobic biological treatment or composting is a common process used to manage olive pomace. It refers to the treatment of the waste using microbial agents to decompose it into usable final products. Microbial activities lead to heat production, which in turn contribute to physicochemical changes of the waste into biomass, CO_2 and a pasty solid end-product. These activities are conducted under aerobic conditions, which can be naturally, manually, or mechanically induced. Often in composting, bulking material, such as wood shaving, poultry and sheep manures or wool waste has to be added to achieve proper moisture level and good aeration of the pulp and, in the case of manure, enhance the nitrogen and phosphorus content of the compost. Fairly low air emissions are produced, while the consumption of energy and resources is insignificant. Composting leads to a significant decrease in phenols content and a noticeable transformation of low to high molecular weight fraction during composting (Rigane H. C. M., 2015). The by-product has been widely used as a soil conditioner/enricher or fertiliser, which showed to improve the chemical and physicochemical properties of the soil. However, the process includes several parameters (moisture, temperature, the aeration/turning strategies, and the choice of bulking agents) that need to be tailor-made and perfected for each situation in order to be beneficial.

5.3.2.1.2 Environmental impacts and cross-media effects

Composting leads to avoiding harmful wastes being landfilled. The resulting by-product can be used as a soil enricher and is easily and beneficially disposed of. In addition, the produced heat can be recycled into the system, avoiding further cost and additional air pollution load. If mechanical turning is used instead of the forced aeration, minimal cost (in energy or capital) is added to the bill.

5.3.2.1.3 Operational data

This biological treatment is easy, safe and relatively cheap to implement. Therefore, it has been a widely used technique.

5.3.2.1.4 Applicability

The financial and technical easiness of the process, coupled with the good quality, environmentally friendly fertilizer that is produced make composting a very appealing and easy to install and operate treatment plan for OMW.

5.3.2.1.5 Economics and financial resources

Because of its operational applicability as well as the valorization of the generated heat and the resulting compost, OMW presents an economically viable and, as previously mentioned, a widely used technique.

5.3.2.1.6 Driving source for implementation

The easiness, both from financial and staffing points of view, as well as the production of a valorized by-product (fertilizer) have been the main drivers behind the appeal of the composting technique.

5.3.2.1.7 Case study: Composting in Guadalcazar, Córdoba/Spain

This case study refers to the "Aceites Coto Bajo EXP Agric. S.A." in Guadalacazar, Cordoba. Around 25,000 m^3 of two-phase wet pomace was composted per year using an area of 30,000 m^2. The inputs consisted of 40% two-phase wet pomace with 40% chicken manure and 20% leaves to produce around 30,000 tons of organic compost per year (Chartzoulakis, 2017).

Some technical problems were faced including the non-homogeneity of raw materials and the bad odours emanating during the start-up period (Chartzoulakis, 2017).

The investment cost amounted to 300,000 € for civil engineering works and 300,000 € for turn over equipment, while the operating cost was around 90 € per week. The production cost of the compost is estimated at 0.05-0.06 €/kg-compost (expected to be reduced to 0.03 €/kg) (Chartzoulakis, 2017).

5.3.2.1.8 Case Study: Pomace composting and use in conjunction with application of raw OMW in Tunisia

Gargouri et al in 2013 discussed the case of OMW in Tunisia, where composting is common practice. In the central urban region of Sfax, 400 mills exist that produce 250 thousand m^3 of OMW/year and around 150 thousand tons of pomace that have been processed in evaporation ponds situated at 350 km away.

Because, the soil in that region is semi-arid receiving on average around 200 mm of rainfall/year, raw OMW was used as liquid fertilizer at 50 m^3/ha. At this rate, the application of OMW did not affect the pH of soil, organic matter level increased by 0.45%, K & P content increased but N content was not affected and the yield of olive trees improved to 83% (compared with previous 12%) within two years of OMW application. With a total cost of 8.1 Tunisian Dinar (TND)/m^3 of OMW spreading (compared to 8,200 TND for the evaporation of vegetable water), this option proved efficient biologically and economically. (1 TND or Tunisia Dinar= 0.49 euro at the time of the study).

When pomace was composted, cow manure locally produced was added at a ratio of 2/1 to reach a ratio of C/N of 35, accompanied by mechanical turning for aeration every 5 to 10 days keeping humidity at 55%. These conditions led to maturation of compost after 110 days.

The compost was spread at a rate of 100 m^3/ha which led to increase in soil fertility, as well organic and mineral soil content and soil electrical conductivity. However, soil pH was not affected and remained slightly alkaline. 36.8 TND were needed for the global cost of one ton of compost, which is a rather high cost compared to other organic fertilizer. As such, OMW as liquid fertilizer was favoured by the farmers over spreading compost from pomace.

Nonetheless, Cossu et al (2013) conducted an environmental impact assessment on pomace produced by two-phase mills. Three scenarios were created (1-combustion for domestic heating, 2- production of electrical energy and 3- composting). Domestic heating and production of electricity were the most important factors impacting human health, the ecosystem and the exhaustion of natural resources. Composting proved to be 2 to 4 times less damaging on human health, the effect on climate change human toxicity and formation of fine particles. All of this has led the authors to conclude that composting of pomace remains one of the best methods of valorization.

In the region of Pouzouita in Sfax, the physicochemical treatment adopted there was producing 20% olive cake and 80% treated water (via nano-flitration till reverse osmosis). The treatment units are mobile but can be fixed with the equipment installed in steel containers with one unit capable of treating 50 m^3/hour.

In Agareb region of Sfax, they opted for bio-methanization, anaerobic digestion to produce electric energy to light the station and thermal energy to use for heating the pomace and drying it, avoiding as such the main disadvantages of the two-phase milling present (Maknisial A, 2010).

FIGURE 1: Photos of pomace composting

	
Composting of pomace and leaves in Idleb Syria	**Mechanical turning of the compost**

Irrigation of compost with vegetable water

5.3.2.2 Fermentation/Anaerobic treatment of pomace

5.3.2.2.1 Description

Anaerobic biological treatment or fermentation is a common process used to manage olive pomace. It refers to the digestion of the effluent using microbial agents under anaerobic conditions leading to the decomposition and conversion of organic materials into biogas, a mixture of methane and carbon dioxide. The bacterial community used works on breaking the recalcitrant biomass structures into their components. The gas produced is often used as fuel, in combination with heat to power a gas engine. Alternatively, it can be upgraded to natural gas-quality bio-methane.

Anaerobic digestion is positively considered because it:

- Requires low nutrient levels;
- Produces a nitrogen-rich digestate that can be used as an agricultural fertilizer;
- Has energy savings potential as heat can be recycled into the system;

- Generates low quantities of sludge;
- Generates energy-efficient and environmentally friendly combustible biogas.

In fact, biogas production through anaerobic digestion has been evaluated as generally one of the most energy-efficient and environmentally beneficial technologies for bioenergy production (Al-Mallahi, 2016).

Various research studies have confirmed that higher methane production rates were observed when higher Organic Load Rate (OLR) was applied (Borja, Rincón, Raposo, Alba, & Martín, 2002) (Rincon, et al., 2006). All in all, it was concluded that anaerobic digestion is a stable, reliable and effective process for energy recovery and stabilization treatment of olive pulp. There has been research into co-digestion of OMSW with OMWW and other organic materials and increased methane yield was observed with co-digestion (Fezzani & Cheikh, 2007).

However, pre-treatment of olive mill waste has often been a necessary first step before proceeding to anaerobic digestion. Properties such as pH, buffer capacity, nutrient content, toxicity must be adjusted to appropriate levels and riddance of inhibiting substances, such as oils and polyphenols, must happen before anaerobic digestion can occur. Such pre-treatment operations include:

- Flotation, gravity settling, or membrane filtration.
- Physical or chemical pre-treatment.
- Phase separation.

Neutralization is also an essential pre-treatment method before anaerobic units, as the methane formation is only possible at a pH range of 6.5–7.6. Neutralization is commonly done by using lime, sodium hydroxide, sodium carbonate, or bicarbonate. O-diphenols, the most phytotoxic components in OMW, can be removed by lime treatment, and this results in a more easily biodegradable effluent. In addition, total solids were removed by 30–55%, volatile solids by 30–65%, oil and grease by 90–98%, polyphenols by 65–76%, volatile phenols by 30–46%, and COD by 32–60%. Ultrafiltration is also a pre-treatment method that removes high levels of lipids and polyphenols and reduces COD level. Centrifugation is more preferable than sedimentation, as it produces smaller volumes of the separated phase.

5.3.2.2.2 Environmental impacts and cross-media effects

Anaerobic digestion turns harmful wastes into usable by-product (heat) and benign, compact sludge, hence majorly reducing the need for landfilling. The produced biomass can be recycled back into the heating system or further treated to be used as a source of energy or heat domestically and industrially. This translates into avoiding further cost and additional pollution air load.

5.3.2.2.3 Operational data

Anaerobic digestion is a relatively easy, safe biological treatment method that does not require a huge capital to implement. Therefore, it has been widely used especially because the heat produced is utilised. However, the pre-treatment requirement adds a layer of complexity and a minor financial burden.

5.3.2.2.4 Applicability

The financial and technical relative easiness of the process, coupled with heat production and fertilizer make anaerobic digestion a relatively easy to achieve treatment option for OMW.

5.3.2.2.5 Economics and financial resources

Because of its operational applicability as well as the valorization of the generated heat, anaerobic digestion presents an economically viable and a widely used technique.

5.3.2.2.6 Driving source for implementation

The easiness, both from a financial and staffing point of view, as well as the production of a valorized by-product (heat, compost, water for irrigation) have been the main drivers behind the appeal of this technique.

5.3.2.2.7 Case study: Anaerobic digestion in Abrantes, Portugal

The application of anaerobic digestion of olive mill waste was implemented in the company LNEG – INETI in Abrantes, Portugal.

The inputs to the plant consisted of 5 tons/day OMW, 46 tons/day activated sludge, 1.5 tons/day of pomace and 2.2 tons/day of municipal organic waste. The outputs of the plant consisted of 300 m^3/day of biogas, 1.6 m^3/day of compost in addition to irrigation water (Chartzoulakis, 2017).

The investment cost amounted to 300.000 € while the operating cost was around 14,000 €/year. The expected income from the plant is around 26,000 € (0.2 € / kWh x 357 kWh/d x 365 d) per year (Chartzoulakis, 2017).

5.4 TECHNIQUES FOR REDUCTION AND MANAGEMENT OF VEGETABLE WATER

Most treatments of vegetable water aim at the reduction of the organic matter and phenolic compounds, hence the reduction of chemical oxygen demand and phytotoxicity, respectively (Galanakis, 2017). However, the difficulties of vegetable water treatment are mainly related to (Galanakis, 2017):

- its high organic load,
- the seasonal nature of the operation of mills,
- vast geographic distribution of mills, and
- the presence of non-biodegradable organic compounds like long-chain fatty acids and phenols.

Many different processes have been suggested to treat vegetable water, including lagooning or irrigation, co-composting, biological and physicochemical methods (flotation and settling, coagulation, oxidation by Ozone and Fenton reagent, flocculation, filtration, sedimentation, dilution open evaporating ponds, and incineration), ultrafiltration/reverse osmosis, chemical and electrochemical treatments and manufacture into animal food. In the following sections the main techniques used are discussed starting with biological treatment.

5.3.3 Biological treatment

Several studies have been developed on biological treatment processes for vegetable water and pomace. This section presents aerobic, anaerobic and combined processes as well as new trends in recovery of value-added compounds from pomace and vegetable waters.

Aerobic biological treatments have been proposed for the treatment of effluents from the production of olive oil using several microorganisms such as *Pleurotus ostreatus, Bacillus pumilus, Chrysosporium hanerochaete, Aspergillus niger, Aspergillus terreus, Geotrichum candidum*, etc… (Ochando-Pulido, Fragoso, Macedo, Duarte, & Ferez, 2016) Ehaliotis et al. used Azotobacter vinelandii to fix nitrogen to produce a vegetable fertilizer (Ehaliotis C., 1999).

Amaral et al. used a strain of Candida oleophila isolated from vegetable water for detoxification (Amaral, et al., 2012). The results show an organic content of 50% and 83% of the total polyphenol content. The germination index increased to 32% compared to the value obtained with untreated vegetable water. Therefore, C. oleophila isolate has been able to detoxify vegetable waters and can be used for future application in biological treatments.

Chiavola et al. studied the efficiency of a sequential batch reactor (RDS) in the biological treatment of previously screened and diluted vegetable water (Chiavola, Farabegoli, & Antonetti, 2014). Four dilution ratios were tested (vegetable water / tap water): 1:25, 1:32, 1:16 and 1:10. The results showed that there was complete elimination of the biodegradable organic content at all the influent loads studied (0.08, 0.11, 0.19 and 0.69 mg of COD), with an average efficiency of about 90% and 60% for COD and phenols, respectively. The authors also tested the addition of a pre or post-treatment using membrane technologies: ultrafiltration, nano-filtration and reverse osmosis. The introduction of membrane separation has made it possible to produce treated wastewater that complies with the limits of Italian legislation regarding COD, pH and electrical conductivity. Phenol concentration did not reach the required limit for reuse. Considering a large-scale application, the option of mixing the waste with other liquid streams to provide the required nutrients as well as the influent loading dilution can be considered.

Anaerobic digestion technology applied on vegetable water not only helps to treat them, but also produces biogas that can be used as a primary energy resource at the local level. For an efficient anaerobic bioconversion process, the wastewater should have a balanced carbon-nitrogen-phosphorus ratio (C / N / P) and a pH between 6.5 and 7.5. Although vegetable water has an unbalanced C / N / P ratio, there are studies of anaerobic digestion of vegetable water as a single substrate (Ammary, 2005), but its mixing with nutrient-rich streams, co-substrates, greatly improves the performance of the process. Several studies evaluate the use of pre-treatment for the removal of recalcitrant compounds prior to the anaerobic digestion process, for example, the advanced oxidation processes or flocculation by coagulation.

González-González et al. performed aerobic pre-treatment prior to anaerobic digestion to remove phenols and reduce COD (González-González & Cuadros, 2015). They observed a reduction of 78% and 90% of polyphenols and 18% and 21% of COD for aeration periods of 5 and 7 days, respectively. The best methane yield (0.39 m^3 methane / kg of removed COD) was obtained with aerated vegetable water for 5 days and was 2.4 times higher than that for untreated vegetable water.

One of the most studied pre-treatments is the use of ultrasound for the deconstruction of biomass; Oz et al. investigated the applicability of low frequency ultrasound technology on vegetable water prior to anaerobic digestion in batch reactors (Oz & Uzun, 2015). The results showed that the application of 20 kHz, 0.4 W / mL for 10 minutes to diluted vegetable water led to a 20% improvement in biogas and methane production in the pre-treated diluted vegetable water tests.

An important aspect to consider when choosing a pre-treatment is the net energy balance; increase in biogas production should clearly offset energy intake. Ruggeri et al. present an interesting approach, comparing several pre-treatment processes based on biochemical methane potential rating (PMB) and energy sustainability index (IDE) (Ruggeri, Battista, Bernardi, Fino, & Mancini, 2015). IDE considers the direct use of energy (heat and electricity) and the indirect consumption of energy, the energy needed to produce chemical reagents applied in pre-treatments. The results showed that the most efficient pre-treatment was the addition of $CaCO_3$, with a biogas production of 21.6 NL / L and an IDE of 14 (that is, the energy obtained in the form of methane is 14 times that of the energy expended).

With regard to the co-substrates studied for co-digestion of vegetable water, manure is one of the most used because it contributes to the nutrient balance, has a high pH and has a high buffer capacity. An example of a recent study is the research of Khoufi et al. who studied co-digestion of vegetable water with liquid poultry manureliquide (Khoufi, Louhichi, & Sayadi, 2015). The authors concluded that the addition of 30% liquid poultry manure gives the best methane yield. Process improvement is likely related to a more balanced nutrient mix and minimization of the inhibitory effect of ammonia and phenolic compound. Pig manure has also been used as a co-substrate in several anaerobic co-digestion studies. Recently, Kougias et al. conducted batch and semi-continuous tests with different mixtures of vegetable water and pig manure (Kougias, Kotsopoulos, & Martzopoulos, 2014). The best results were obtained using 40% vegetable water in a semi-continuous reactor.

Sampaio et al. tested the use of a high-throughput anaerobic hybrid digester reactor for the digestion of vegetable water (Sampaio, Gonçalves, & Marques, 2011). An organic loading rate of 8 kg COD / m^3 / day provided 3.7-3.8 m^3 of biogas per m^3 per day (63-64% of CH_4) and 81-82% of COD removal. They also tested the reactor feed with alternating pork slurry and vegetable water, resulting to a biogas production of 3.0-3.4 m^3 per m^3 per day (63-69% CH_4).

Another approach for the bioconversion of vegetable water to energy is its use for the production of hydrogen and bioethanol by anaerobic fermentation. Eroğlu et al. studied *Rhodobacter sphaeroides* for photofermentation of vegetable water under anaerobic conditions, obtaining a hydrogen production of 16 L H_2 per Liter of vegetable water (Eroglu, Eroglu, & Yucel, 2008). More recently, Battista et al. used a mixture of vegetable water and olive-pomace to produce hydrogen and bioethanol by the anaerobic fermentation of *Saccharomyces cerevisiae* (Battista, Mancini, Ruggeri, & Fino, 2016). They also tested different pre-treatments (ultrasound, alkaline hydrolysis and addition of calcium carbonate), concluding that ultrasound and alkaline pre-treatment lead to the hydrolysis of lignin and cellulose. This fact leads to the increase of soluble organic matter (i.e. sugars) by improving the production of methane. The addition of calcium carbonate has helped to optimize the process by eliminating polyphenols, which are inhibitors of the fermentation process.

Vegetable water is considered a source of biologically active phenols (biophenols) because of its high content of phenolic compounds, widely recognized as antioxidants that can be used in many industries, for example food and pharmaceutical production companies. A recent study by Kaleh and Geißen describes the use of acidification, sedimentation and membrane filtration of vegetable waters for the recovery of biophenols, namely, hydroxytyrosol, tyrosol, caffeic acid, oleuropein and luteolin (Kaleh & Geißen, 2016). Synthetic resins and molecularly imprinted polymers have been tested as sorbents and the results have shown that by combining different pre-treatments with sorbent options, it is possible to selectively adsorb specific biophenols.

Goula and Lazarides present an integrated approach aimed at the complete recovery of precious vegetable water constituents and the reuse of the water flow that has been cleaned up in the oil mill (Goula & Lazarides, 2015). Specially designed fermentation, spray-drying and encapsulation technologies are used to produce a number of valuable bioproducts, such as olive paste or olive powder (to be included in food formulations) and encapsulated phenols.

Federici et al. discussed several strategies for vegetable waters such as the recovery of antioxidants by chemical methods and the fermentative production of enzymes of commercial interest (Federici, Fava, Kalogerakis, & Mantzavinos, 2009).

Mateo and Maicas reviewed the most promising microbiological processes for the valorization of by-products of olive oil production (Mateo & Maicas, 2015). According to the authors, microbiological processes have interesting potential because they have less impact on the environment and, in most cases, can be profitable. The relevance of this analysis is that they lead to value-added products such as enzymes, biofuels, biopolymers, etc.

In fact, vegetable water, because of its characteristics, has been used in several studies as a means to develop microbial species that consume organic matter and simultaneously produce biomass and other bio-products, such as enzymes and organic acids.

Ntougias et al. focused on the microbial treatment of vegetable water, evaluating the use of 49 strains of white fungi belonging to 38 species of Basidiomycota (Ntougias, et al., 2015). The results showed a reduction of the total phenols up to 60% and a colour up to 70%. The authors also evaluated the efficiency of the combination of photocatalytic oxidation, using two nanomaterials as catalysts (TiO_2 and Fe_2O_3), with biological degradation by fungi (*Pleurotus sajor caju and P. chrysosporium*). The most effective detoxification process was the combination of Fe_2O_3/ UV with *P. chrysosporium*, with a reduction of about 37% and 96% for COD and phenol, respectively.

Vegetable water has been used for the production of algae biomass as well, which accumulates lipids and carbohydrates and can therefore be used for the production of biofuels or the recovery of compounds. Di Caprio et al. used vegetable waters supplemented with nitrates (to avoid a reduction in the specific growth rate) for the cultivation of *Scenedesmus sp.* production of biomass and depuration of the vegetable water (Di Caprio, Altimari, & Pagnanelli, 2015).

5.3.4 Thermal processes

5.3.4.1 Evaporation/distillation

Physico-thermal processes consist of evaporation and distillation of vegetable water where a concentrated solution — ‘‘molasses’’ or concentrated ‘‘paste’’ — and a volatile stream consisting of water vapor and volatile substances are produced.

Evaporation differs from distillation in that when the volatile stream consists of more than one component, no attempt is made to separate these components.

In evaporation, vegetable water is separated into a residue containing non-volatile organics and mineral salts, and a condensate that consists of water and volatile substances.

The evaporation of vegetable water reduces its volume by at least 70 to 75% and bringing down the polluting load to more than 90% in terms of COD (Di Giacomo G., 1999). It makes the storage and handling of residue much more feasible and easier than when it is still in liquid shape. In addition, evaporation and/or distillation give a large reduction also to BOD_5 and with only one more step of treatment such as the biological treatment, the much smaller in size and volume residues, can be safely disposed of in mainstream waste routes (Niaounakis & Halvadakis, 2006).

The main technique for evaporation and distillation along with the overall needed information is discussed herewith:

5.3.5 Evaporation ponds or lagoons

5.3.5.1 Description

Vegetable water is disposed of in large lagoons (artificial evaporation ponds or storage lakes). Solar energy is used to speed-up the process of evaporation and drying of vegetable water.
Moreover, vegetable water is partially degraded by a natural biological route, over long periods of time (around 7–8 months), in practice, from one milling season to the subsequent season, depending on the climatic conditions of the area. It has been estimated that for every 2 tons of olive processed, 1 m^3 of lagoon volume is required for storage and natural evaporation in Izmir, Turkey (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004) (Kasirga, 1988) (Niaounakis & Halvadakis, 2006). Lagooning has been used for pollution control and vegetable water disposal as fertilizer after solar drying (Leon-Cabello R., 1981) and for storage in order to obtain load equalization during the whole year before the treatment by other processes (Balice V., 1986). Removals of COD ranging from 20–30 to 75–80% have been obtained after 2–4 months (Niaounakis & Halvadakis, 2006).

5.3.5.1.1 Environmental impacts and cross-media effects

Evaporation ponds or lagoons have the following drawbacks:

- Risk of vegetable water leaking through the soil into the groundwater. Using proper liners and suitable maintenance is vital for the proper functioning of the lagoon.

- They require the availability of large collecting basins at a distance from residential areas due to the unpleasant smell of vegetable water and its anaerobic fermentation producing a strong acetic acid smell and the presence of insects.
- The lagoons may have to be located 1 or 2 km away from the olive mill, so proper piping is needed to transport the vegetable water to prevent possible leakage into the soil.

Considering the large volumes of vegetable water produced yearly during a short period of time, large surface areas should be made available for long periods (about $1m^2$ for each 2.5 m^3 of vegetable water); consequently, these large land surface areas are rendered useless for active agriculture.

5.3.5.1.2 Operational data

Lagooning, when done properly requires large surface areas and good sealing of the bottom and edges of the lagoon and as such, material and labour force (available and easy to install) have to be factored in when deciding on the operationality of the process. Having said that, the designs and height of an evaporation pond must take into consideration, among other factors:

- Volume of vegetable water produced by each of the olive-mills to be serviced,
- Climate of the region,
- Hydrology of the ground,
- Proximity of natural waters,
- Distance from residential areas.

5.3.5.1.3 Applicability

Most Mediterranean countries dispose of OMWW in artificial evaporation ponds, the most developed being evaporation ponds provided with an impervious layer and those that use soil as a receptor medium, for instance, evaporation and infiltration ponds for large amounts of vegetable water (Escolano Bueno, 1975) (Niaounakis & Halvadakis, 2006).

5.3.5.1.4 Economics and financial resources

Areas with frequent and intense rainfalls require large evaporation areas.

The excavation costs comprise digging operations and removal of unearthed soil. The estimation of the excavations' costs (between 7 and 20 Euros per m^3) is difficult because it depends on the type of the soil and the distance from the disposal site.

The following costs have been proposed for the purchase and the placing of the lining material (Le Verge S., 2004):

- Anchoring trench: 7.5 €/m;
- Draining geotextile with anti-piercing characteristics: 6 €/m^2;
- Geomembrane of high density polyethylene (HDPE) with a thickness of 1.5 mm: 7 €/m^2;
- Draining geotextile with anti-piercing characteristics: 6 €/m^2;
- Layer of intermediate material (e.g. coarse gravel, flintstones, or cobbles): 2 €/m^2;
- Removal cost of the unearthed soil: layer of pebbles: 2 €/m^2.

In addition, the cost of sealing a pond of 1000 m^2 is estimated at 20,000 €. This cost is reduced at 16,000 €, if the cleaning of the pond is made with the help of a ditch cleaning machine.

5.3.5.1.5 Driving force for implementation

When done properly, through proper piping and lining, lagooning presents the advantages of low investment and maintenance cost for a treatment solution for vegetable water.

FIGURE 2: OMWW evaporation pond

Evaporation pond (Koura, Lebanon)

5.3.6 Physico-chemical and advanced oxidation processes including new developments

Sarika et al. studied pre-treatment of vegetable waters by flocculation with cationic and anionic polyelectrolytes (Sarika, Kalogerakis, & Mantzavinos, 2005). Most flocculants tested, completely removed suspended solids and significantly reduced COD and BOD_5. The authors suggest the post-treatment of the liquid phase by means of high-power ultrasound, advanced oxidation, biological processes or a combination of these, whereas for the solid fraction, they declared that various solid agro-waste can be composted to produce soil fertilizer.

Khufi et al. studied the recovery of vegetable waters for agricultural purposes using electro-fenton followed by anaerobic digestion (Khoufi, Aloui, & Sayadi, 2006). Up to 65.8% of the total phenol concentration could be eliminated by electro-Fenton, and a 33.1% reduction in toxicity was ensured. Electrocoagulation of the digested anaerobic effluent provided complete detoxification.

Tezcan et al. applied electrochemical oxidation with PAC in the presence of H_2O_2 on fresh vegetable water (COD 45,000 mg/l) (Tezcan Un, Ugur, Koparal, & Bakır Ogutveren, 2006). The results obtained revealed that the Fe electrode was more efficient than the Al electrode. Next, Tezcan et al. investigated the electrochemical oxidation of vegetable waters using the Ti / RuO2 anode on samples of vegetable water from an oil mill using 3-phase technology (Tezcan Un, Altay, Koparal, & Bakir Ogutveren, 2008). Removal rates of organic materials increased with increasing applied current density, sodium chloride concentration, recirculation rate, and temperature. The treated vegetable water effluent showed a final COD of around 167 mg/l (99.6% removal efficiency) and almost complete reduction of phenolic compounds. The operating costs estimated by the authors were equal to 0.78 €/kg of COD.

Flocculation of coagulation is a common pre-treatment, and research has investigated alternatives to conventional chemicals, using biopolymers such as chitosan or residues from other industrial activities (Rizzo, Lofrano, Grassi, & Belgiorno, 2008).

Pham Minh et al. studied wet catalytic oxidation of vegetable water with titanium or zirconium based on platinum and ruthenium, coupled with anaerobic digestion (Minh, Gallezot, Azabou, Sayadi, & Besson, 2008). The authors reported effective removal of total organic carbon up to 97%, and almost complete elimination of phenolic content.

In addition, Chatzisymeon et al. studied the photocatalytic treatment of vegetable waters from 3-phase extraction systems with TiO_2 in a photo-reactor at the laboratory scale (Chatzisymeon, Xekoukoulotakis, & Mantzavinos, 2009). They found that COD removal was improved by contact time and also affected by affluent COD, while all other variables were not statistically significant for COD removal. It has been noted that TiO_2 photo-catalysis may be a promising process for the treatment of vegetable waters.

Justino et al. examined the efficacy of a combined treatment process sequentially comprising fungi with *Pleurotus sajor caju* and photo-Fenton oxidation or vice versa (Justino C. I., 2009). Fungus treatment was performed on diluted vegetable water samples, after which the reduction of acute vegetable watery toxicity to *Daphnia longispina* was confirmed, providing 72.9% removal of phenolic compounds and 77% reduction of organic matter (COD).

Cañizares et al. evaluated and compared the technical and economic possibilities of three advanced oxidation processes: electrochemical conductive diamond oxidation, ozonation and oxidation of Fenton, for wastewater polluted with different types of organic compounds, including vegetable waters (Cañizares, Paz, Sáez, & Rodrigo, 2009). According to their results, only the electrochemical oxidation of conductive diamond could achieve a complete reduction of organic matter (mineralization) pollutants for all waste. However, it has been found that efficiency depends on the concentration of specific pollutants, while oxidation with ozone (at pH 12) or Fenton's reagent depends on the nature of the pollutants. The estimated average operating costs were around 2.4-4.0 €/kg O_2 equivalent for the electrochemical oxidation process of conductive diamond, 8.5-10 €/kg O_2 equivalent for ozonation, while 0.7-3.0 €/kg O_2 equivalent for the oxidation of Fenton.

El-Gohary et al. studied the integration of catalytic oxidation with wet hydrogen peroxide before a two-stage up-flow anaerobic sludge blanket for the treatment of vegetable water (El-Gohary, Badawy, El-Khateeb, & El-Kalliny, 2009). The flow of raw vegetable water was diluted with tap water and pre-treated by the reaction of Fenton with $FeSO_4$.

In a similar line, Walid et al. studied various combined processes for the treatment of vegetable waters, including advanced oxidation by UV and/or O_3, and aerobic biodegradation (Lafi, Benbella Shannak, Al-Shannag, Al-Anber, & Al-Hasan, 2009). The results showed that for step 2 treatment of O_3 and the two step O_3 /UV treatment, the COD remained quite high. The combination of advanced UV/O_3 oxidation followed by a biodegradation process resulted in the highest COD reduction efficiencies of up to 91%.

Azaboua et al. examined a compact process for the treatment of vegetable water including catalytic oxidation with hydrogen peroxide followed by different biological techniques (Azaboua S., 2010). The results obtained revealed that the flow of raw water was resistant to the photocatalytic process, but a considerable reduction of the concentrations of COD, colour and phenolic compounds was reached throughout the process.

Papastefanakis et al. investigated electrochemical oxidation water harvesting using cyclic voltammetry and bulk electrolysis with Ti / RuO_2 and Ti / IrO_2 anodes (Papastefanakis, Mantzavinos, & Katsaounis, 2010). The elimination of eco-toxicity and up to 86 and 84% color and phenol removal, as well as 52% and 38% COD and total organic carbon reduction, respectively, could be successfully achieved.

Stoller and Chianese have studied the purification of vegetable water to comply with municipal sewer discharge standards (Italy) (Stoller & Bravi, 2010) (Stoller & Chianese, 2006). The authors proposed a treatment process involving initial flocculation of coagulation with aluminium sulphate or aluminium hydroxide followed by discontinuous ultrafiltration and nano-filtration in series with layered thin spiral membranes. Both pre-treatment processes yielded similar COD and BOD_5 rejection efficiencies. However, higher productivity was achieved in the subsequent process of the membranes in series after flocculation with aluminium sulphate. After that, Stoller carried out a further study on flocculation as pre-treatment of microfiltration membranes, ultrafiltration, nanofiltration and reverse osmosis in the treatment of three-phase vegetable waters, examining the particle size distribution in the effluent at the exit of each stage (Stoller, 2009). Stoller pointed out the effect created by secondary flocculation induced by the flocculant-derived salts (aluminium sulphate) that accumulate near the membrane surface. This fact improves the particles to be carried away by the tangential flow, thus substantially reducing the fouling. In a subsequent research paper, Stoller and Bravi applied the same coagulant flocculants to pre-treat the margins of 3-phase systems prior to microfiltration, ultrafiltration, nano-filtration and reverse osmosis applied in sequence (Stoller & Bravi, 2010). In addition, they examined photo-catalysis (PC) with nanometric titanium dioxide in anatase form irradiated with ultraviolet light and aerobic treatment. All pre-treatment processes provided definitive reverse osmosis permeate currents in accordance with irrigation quality standards (COD ranging from 242 to 456 mg / L). However, UV / TiO_2 photo-catalysis showed the highest productivity of the membrane in the shortest residence time (24 h).

Martínez-Nieto et al. tested the Fenton chemical oxidation process using ferric chloride or potassium permanganate as a catalyst for H_2O_2 activation on an industrial scale (Martínez Nieto, Hodaifa, Rodríguez, & Giménez, 2010). Using potassium permanganate in the system, the final water was transparent with a slight yellow tint, but odourless with a low total phenol content. The sediments in the decanter were rich in manganese dioxide (MnO_2), which, although non-toxic, would require additional management. Finally, the versatile design of the plant offers the possibility of working with both oxidation systems, without having to modify the procedure. The produced water could be used for irrigation or discharged directly into the municipal sewage system.

In 2011, the above mentioned authors studied an advanced oxidation process based on the Fenton reaction for the degradation of the organic matter load present in the vegetable waters produced by the two-phase olive oil extraction process (Martínez Nieto, Hodaifa, Rodríguez Vives, Giménez, & Ochando, 2011). The same authors have shown that organic matter is efficiently degraded by a Fenton type reaction using $FeCl_3$ as a catalyst in the presence of hydrogen peroxide. Organic compounds and phenolic compounds were removed by up to 95%. These results revealed a Fenton-type reaction as a relatively inexpensive solution for the treatment of waterweed. The treated water from this process was suitable for irrigation.

Ochando-Pulido et al. studied the photocatalytic degradation of vegetable water at the laboratory scale (Ochando-Pulido, Hodaifa, Víctor-Ortega, & Martínez-Férez, 2013). The main technical-economic obstacle is the difficulty of recovering the catalyst. To solve this problem, a new nano-photovoltaic photo-catalyst with ferromagnetic properties has been developed. This new photo-catalyst offers good results compared to other commercial PCs. Up to 58.3% removal of COD, 27.5% removal of total phenols and 25.0% removal of suspended solids were achieved. In addition, if pre-treatment of the pH-pH flocculation was performed, the overall COD suppression efficiency increased to 91%. According to the results obtained in this investigation, the process of photocatalytic degradation is an alternative with great possibilities in the treatment of vegetable waters.

Ruzmanova et al. recently examined the treatment of vegetable waters of 3-phase systems by photocatalysis with N-doped TiO_2 sol-gel material (Ruzmanova, Ustundas, Stoller, & Chianese, 2013). The adopted doping procedure was validated under visible light, showing superior performance over undissolved particles, which resulted in more than 60% removal of COD. Photocatalysis assisted by a visible light-sensitive TiO_2 catalyst may represent a very promising solution for the degradation of organic compounds in vegetable water and similar effluents.

In a different research work, Papaphilippou et al. have proposed an integrated treatment process for vegetable waters consisting of sequential coagulation-flocculation, phenol extraction and post-oxidation by photo-Fenton (Papaphilippou, et al., 2013). After the photo-Fenton oxidation, about 73 ± 2.3% was removed and total phenols of 87 ± 3.1% were found respectively. In addition, comparative phytotoxicity tests revealed that more biologically potent products were obtained during oxidation.

Michael et al. addressed the purification of vegetable waters from 3-phase systems by means of an advanced solar oxidation process combined with prior coagulation/ flocculation, allowing high COD removal (87%) and removal of the polyphenolic fraction. The overall cost of Fenton solar oxidation was 2.11 €/m^3 (Michael, Panagi, Ioannou, Frontistis, & Fatta-Kassinos, 2014).In a recent study, Alver et al. studied a sequential system including coagulation and Fenton reaction (Alver, Bastürk, Kılıc, & Karatas, 2015). Higher treatment efficiency was achieved through sequential coagulation and the Fenton system. This study demonstrated that integrated coagulation and the Fenton process could be a potential solution for the effective removal of phenolic pollutants from this type of wastewater.

However, as most of these methods require expensive materials and devices as well as highly skilled labour force, they have remained on laboratory or pilot scale and are yet to be implemented on an industrial level. As such, these techniques will not be further analysed according to the adopted methodology pursued so far.

5.3.7 Direct application in agriculture and use as biocides and herbicides

Vegetable water has been used as a soil amender with antimicrobial activity and suppressive effects against plant pathogens (Brenes M., 2011). Several studies reported the potential of using vegetable water as bio-pesticides against plant pathogens (Yangui T., 2013) (Debo A., 2011). It can be used to suppress the growth of the main weed species (*Phelipanche ramosea, Amaranthus retroflexus Avena fatua, Alopecurus myosuroides*, among other species) without any negative effects on crop growth (Boz O., 2010) (Disciglio G., 2015). Similarly, vegetable water has been proven effective against the main bacterial (i.e., *Clavibacter michiganensis, Erwinia toletana, Erwinia amylovora*) and fungal (i.e., *Aspergillus niger, Botrytis tulipae, Fusarium oxysporum, Penicillium* spp.) phytopathogens (Medina E., 2011) (Lykas C., 2014). Besides, studies reported the biocide effect of vegetable water on some pests, molluscs (*Isidorella newcombi*) (Cayuela et al., 2008), nematodes (Meloidogyne incognita) (Obied H.K., 2007) and arthropods (*Aphis citricola, Euphyllura olivine*) (Larif M., 2013).

Based on the available studies, vegetable water can be utilized in agriculture for plant diseases control, in which case a by-product that is typically regarded as waste can be beneficial and useful. However, some measures regarding the dose and timing of use should be respected.

In fact, it was demonstrated that the controlled spreading of raw wastewaters on agricultural land may have a positive effect on the olive plantations, as well as on other crops such as grape wine, corn or sunflower. However, this practice is to be considered only after a thorough evaluation of all of the environmental impacts. For example, experiments with 1000 m^3 ha^{-1} per year or more of raw wastewaters laid on limestone containing Spanish soils have resulted in an increase in organic matter, total and soluble nitrogen, available phosphorus, and salts. But it also increased the mobility of heavy metals, and caused lixiviation of sodium and nitrate into deep soil, which are unwanted effects. On the other hand, when low wastewater volumes, such as of the order of 100 m^3 ha^{-1} per year are used, it is suggested that the soil could act as a bio-filter for the treatment of olive oil wastewaters (Azbar, Bayram, Filibeli, Fusun, & Ozer, 2004).

As shown above, vegetable water is not just an undesirable by-product that requires elimination. Below is an example of how vegetable water has been used for irrigation in Syria to further illustrate the applicability and importance of valorization.

5.3.7.1 Case Study: Irrigation with vegetable water in Syria

Irrigation with vegetable water is a common practice in Syria and in-depth consideration were studied and implemented in Idlib and Daraa areas. The conclusion that was reached is that the application of vegetable waters from traditional and three-phase mills is beneficial to the fruit trees and the soil if only the following rules are followed:

- Vegetable water has to be equally spread at 50 m^3/ ha (from traditional press) and 80 m^3/ha (from three-phase)
- Vegetable water should be added to fruit trees, leaving a distance of 50-70 cm from the trunk
- Water should be added 30-60 days before planting and 30 days before implants

- Irrigation with vegetable water should be done at least 500 m away from urban areas, and 1,000 m away from any drinking water sources
- Vegetable water should not be used for irrigation in soils with ground water level at 10 m depth (or less), over-flooded or richly watered soils, in riverbanks and stream sides or in roughly inclined terrains.

Following these guidelines, Daraa agricultural landscape has improved with savings resulting from using vegetable waters as well as the savings in Environmental Degradation Cost avoided by using the by-product.

FIGURE 3: Irrigation with OMWW

Irrigation with vegetable water using a closed truck in Idleb Syria

5.3.8 Case Study: Olive mill waste management in Lebanon

Below, we provide a case study based on the Lebanese olive oil extraction experience where two studies have been conducted and looked at the applicability of different techniques and systems that have been discussed above and as such, this case study provides a good hands-on summary of the issues discussed above. It also proves that studies, though necessary, are not enough for addressing the OMW issue if not coupled with political will.

In 2008, the Lebanese Ministry of Environment looked at the different possibilities to be implemented in order to improve the management of olive oil milling situation in Lebanon (MoE, UNDP, EU, 2008). They proposed several scenarios and conducted a Cost Benefit Analysis (CBA) to decide on the applicability and use of each. The options included switching all of the 88% of existing mills (that are traditional press) to two-phase mills, lime pre-treatment of OMW and use OMW for irrigation.

They found out that to reuse the OMW generated in Lebanon for irrigation, they need only 4-10% of olive cultivated land. This translates into a decrease in water irrigation cost, as well as OMW treatment cost. It also leads to a decrease in the overall cost of environmental degradation and an increase in annual savings in fertilizers usage between 400 thousand to 900 thousand USD making this option a desirable one.

For the lime treatment proposal, it was found that this application will cost between 70 and 350 USD/mill/season amounting to around 1000 to 1500 USD/mill to include dosing system, aerators and mixers. The benefit is the production of less polluted water for irrigation purposes and a sludge that can be dried and used as domestic heating source. All considered, this option proved feasible and beneficial especially in the presence of financial assistance.

However, the third option, to replace 414 traditional mills with two-phase mills expenses were calculated to come to 76.6 million USD, while benefits with Cost of Environmental Degradation to reach around 74 million USD and without Cost of Environmental Degradation to be 151 million.

This option turned out not to be feasible if only the operational benefits are accounted for. Such benefits are most likely felt by the mill operators and have direct influence on their judgement and decisions. However, incorporating the benefits through reduction in the cost of environmental degradation, the option might become more feasible, but still not attractive enough to persuade mill owners to adopt it.

SCP/RAC in collaboration with the CARTIF Foundation took the above proposals in case study 2 and argued against all these proposed treatments as they contribute to partial solutions. They suggested the implementation of an integrated treatment plant with treatment phases and post treatment facilities (SCP RAC; CARTIF Foundation, 2008).

The treatment phases include a mechanical drying step, followed by a quick separation of solid waste phase and finishing with a thermal concentration process. Whereas, the post treatment plant includes a composting plant and a manufacturing liquid for organic fertilizers plant.

This integrated plant, and in particular the de-stoning systems, will produce material with high calorific value of $4x10^3$ Kcal/Kg, which means it can be used as a biofuel. In addition, it will improve the yield and quality of produced oil and produce solid waste that is suitable for composting. The concentrated liquid waste produced will be suitable for organic liquid fertilizer and inorganic liquid fertilizer. Finally, water used in the system can be used for irrigation with no water lost as vapour.

Nonetheless, and even in the absence of a national strategy on OMW certain basic techniques can be used to control the amount of waste produced by reducing consumption of water and energy within the systems employed. Energy and water fed into the system can be recycled and re-used in addition to using the waste itself to produce energy and water to feed into the system or to be utilized in heating and agriculture. In chapter 5.5, a list and brief description of the basic techniques used to achieve that is provided.

6. BEST ENVIRONMENTAL PRACTICES

As defined in the Stockholm Convention in 2009 (subsequently amended at the Conference of the Parties in Geneva meetings of May 2009, April 2011, April-May 2013, May 2015 and April-May 2017) BEP or Best Environmental Practices refer to the application of the most appropriate combination of environmental control measures and strategies. BEP run within and alongside BAT to provide as as-complete-as-possible cycle to following a circular economy model and achieving sustainability.

6.1 TECHNIQUES FOR REDUCING WATER CONSUMPTION

Some best environmental practices can be adopted to reduce water consumption in olive mills especially during olive washing and horizontal centrifugation as follows. A water audit can be conducted and water meters can be installed to monitor water quantities consumed by the different processes during olive oil production.

6.1.1 Use of a closed olive washing system

A closed cleaning system which recycles used water is highly promoted, which has also a positive impact in energy savings (Tsarouhas, Achillas, Aidonis, Folinas, & Maslis, 2015).

6.1.2 Control of water flow during horizontal centrifugation

It is important to reduce the use of water during horizontal centrifugation so that the water added does not exceed 20% of the weight of the olives.

6.2 TECHNIQUES FOR REDUCING ENERGY CONSUMPTION

Alternative improvements leading to effective and rational management of energy consumption could reduce energy needs and corresponding atmospheric emissions. Such interventions include best environmental practices that can be as simple as improvements in the combustion process, better insulation or use of automatisms, exploitation of the thermal content of the escape gases and use of efficient energy equipment. The use of renewable energy sources such as solar energy or pomace for heating water is also recommended. It is worth pointing out that, although most of the available solutions of energy savings require a relatively modest investment, their advantages on both environmental and economic performances are significant.

Olive mills can manage energy use throughout all operations by putting in place a comprehensive energy management system, installing meters (where appropriate, smart meters) at the individual process level, carrying out regular energy auditing and monitoring, and implementing appropriate energy efficiency solutions for all processes (Dri, Antonopoulos, Canfora, & Gaudillat, 2018).

6.3 NOISE REDUCTION

Noise pollution in the olive oil industry is considered a major occupational hazard with internal noise levels exceeding 90 dB(A).

Outdoor noise levels could be a public nuisance if the mill is adjacent to residential areas and operations continue during the day and night.

To control noise pollution to a minimum necessary, few steps can be implemented and start ideally with an environmental noise assessment and subsequent management plan. Steps for such a plan include placement of noisy equipments in enclosed spaces, operating them during the day, installing natural and man-made barriers and of course providing noise-cancelling and personal protective equipment to the employees.

6.4 REDUCTION OF AIR EMISSIONS

Air pollution can be caused by the spreading of OMWW on agricultural land as fertiliser, which results in the emission of phenols. Air pollution is also caused by the production of SO_2, methane and hydrogen sulfide from the fermentation of vegetable water when stored in open ponds or discharged on soil or water bodies. In addition, offensive odour occurs from anaerobic decomposition of pomace with high moisture content (such as in the case of the two phase system).
Finally, emissions from mill's equipment and vehicles transporting raw material and end products add to the air pollution load in and around the mill.

In order to tackle air pollution hazards, several BEPs can be implemented as follows:

- Spreading vegetable water on soil in the afternoon because phenols' emissions were found to be much lower in this case.
- Proper maintenance of evaporation ponds and the introduction of an aeration system to reduce odours and air emissions.
- Avoiding storage of pomace in open areas, leading to odour nuisance.
- Properly managing increased traffic during the olive season, and asking all delivery trucks and cars to turn off their cars when they drop off their olive stocks and wait for their olives to be pressed.

7. SELECTION OF THE BEST AVAILABLE TECHNIQUES (BAT) AND BEST ENVIRONMENTAL PRACTICES (BEP) IN THE FRAMEWORK OF CIRCULAR ECONOMY

7.1 ANALYSIS AND CIRCULAR ECONOMY FRAMEWORK

As is specified in the title of the report, these BAT/BEP apply to the olive oil production sector concerning waste minimization, water and energy consumption and valorisation of the sub-products of the olive oil production.

These BAT do not refer neither to the agricultural aspects of olive tree cultivation, nor to the collection methods of olive fruits. In addition, the resulting by-products from these two activities, though sometimes combined with olive oil extraction process' by-products, are not included as a category in the present study.

In the previous chapters, we provided a review of the systems currently used to extract olive oil. We also reviewed the techniques used to treat resulting wastes at all scales, be it industrial, pilot or laboratory. We have accordingly dissected each technique that is industrially applied, to the parameters listed in TABLE 9 of the previous chapter.

It is important to note here that the techniques covered in these BAT conclusions are neither prescriptive, nor exhaustive in any way.

In this chapter, we provide the analysis based on these parameters in order to be able to select the optimal techniques for treating OMW in the MENA region.

It is very important to note here that:

Although this report is about advising on a general *modus operandi* that can possibly be adopted in all contexts and adjusted as need be, it is crucial to note that the MENA region exhibits many variations (topography and geography, political systems, economic and social considerations) and conditions where no 'one fit-for-all' solution can be applied. Therefore, it is emphasized that "contexts" (physical, social, economic, political and environmental) have to be taken into consideration when advising on which solution works best in each situation.

The extraction technique remains the main parameter determining the concentration and physicochemical/ biological nature of the produced wastes. Therefore, as shown in the previous chapter, the focus in deciding on the best solution to manage OMW will be on the used technique and whether or not the said technique needs to be modified or altogether changed.

In case of unattainable local data (where such data does not exist or has not been made available), a common-sense approximation based on international data with appropriate adjustments has been made.

For practical reasons, variations among mills using the same operating systems have been omitted.

Techniques that are applied on experimental or pilot scales have been left out of the present analysis.

Given the above-mentioned points, the analysis is conducted within the most adopted/applicable extraction techniques and these are:

- Traditional press system
- Three-phase continuous system
- Two-phase continuous system
- Two-and-a-half phase system
- De-stoning system

Taking these assumptions and points into consideration, the BAT/BET conclusions presented in this report aim to be applied to all mills, and cover:

- Water efficiency
- Energy efficiency
- Liquid waste management
- Solid waste management
- Noise pollution

However, after conducting the analysis, it became obvious that water and energy efficiency techniques across the different milling systems are similar, as well as noise pollution control steps. Therefore, a summary table is provided below for these three elements, followed by the variations around solid and liquid waste techniques according to each system.

Before proceeding, however, it is important to explain herewith the underlying concept of these control steps, which is that of Circular Economy (CE).

Circular economy aspires to unite generations in the commitment towards a more innovative and promising future and as such a better world. It focuses on the design and redesign of not only products but also processes in order to minimize negative environmental impacts of both processes and products. Findings across a variety of studies reveal that CE can lead to not only pursuing environmental but also economic sustainability.

Adopting circular economy means that materials need to be returned to the production cycle through their re-use, recovery, repair and recycling.

As will be seen from the following paragraphs, the recommendations for the management and treatment of OMW heavily rely on the principles of circular economy. This is especially obvious in the example of water and heat consumption but permeates throughout the recommendations. Valorisation of the operations' by-products also respects the principles of circular economy. Using the seeds as a heat source or the direct application of vegetable water and the composting of pomace as pesticide or to fertilize and enrich the land or as important component in the tanning industry are additional examples.

Overall, the BAT included in this report fall within the remits of a circular economy model and deal with water and energy reduction and noise pollution in addition to the possibilities of waste minimization, by-product revalorization, and efficient management of wastewater from the olive mill.

7.2 BEP FOR WATER, ENERGY, NOISE AND AIR EMISSIONS IN OLIVE OIL PRODUCTION

Generally speaking, and with minimal variations across the different milling systems: BEP to reduce water consumption include one or a combination of the following techniques.

TABLE 11: BEP to reduce water consumption

Technique	Applicability
Conducting a water audit	Generally applicable, if technically and economically feasible
Installing water meters to monitor water consumption	Generally applicable, if technically and economically feasible
Minimising leaking and spilling	Generally applicable, especially if equipments are well maintained and regularly serviced
Re-using washing and cooling water	Generally applicable. However, some periodic, partial or full discharge maybe necessary
Operating a closed-water system	Generally applicable, if technically and economically feasible

In terms of energy efficiency, BEP to reduce energy consumption include one or a combination of the following techniques:

TABLE 12: BEP to reduce energy consumption

Technique	Applicability
Conducting energy audits	Generally applicable, if technically and economically feasible
Installing meters at individual process level	Generally applicable, if technically and economically feasible
Minimising leaking and spilling	Generally applicable, especially if equipments are well maintained and regularly serviced
Use of energy efficient equipment	Generally applicable, if technically and economically feasible
Use of renewable energy sources	Generally applicable, if technically and economically feasible
Proper insulation of equipment	Generally applicable, if technically and economically feasible
Improvement in the combustion process and the use of automation	Generally applicable, if technically and economically feasible

For reducing/addressing noise pollution, the following BEP could be applied:

TABLE 13: BEP to reduce noise pollution

Technique	Applicability
Make an environmental noise assessment and formulate a noise management plan	Generally applicable, requiring technical know-how and minimal finance. Subject local conditions and requirements
Place noisy equipment in an enclosed space or structure	Easily applicable requiring minimal cost
Noisy activities to be carried out during the day and ideally outdoors	Easily applicable requiring no cost
Use natural barriers between the installation and the nearest receptor	Generally applicable. As per local situations
Provide employees with personal protective equipment	Generally applicable, requiring minimal finance

For reducing/addressing air emissions, the following BEP could be applied:

TABLE 14: BEP to reduce air emissions

Technique	Applicability
Spreading vegetable water on soil in the afternoon	Easily applicable requiring no cost
Proper maintenance of evaporation ponds and the introduction of an aeration system	Generally applicable, if technically and economically feasible
Avoiding storage of pomace in open areas, leading to odour nuisance	Easily applicable with minimal cost
Properly managing increased traffic during the olive season, and asking all delivery trucks and cars to turn off the engine when they drop off their olive stocks and wait for their olives to be pressed	Easily applicable requiring no cost

7.3 WASTEWATER/ VEGETABLE WATER

7.3.1 BAT for OMW

As seen in Chapter 2 and 4, mills, with the exception of two and two-and-a-half phase system mills, produce a solid waste called olive cake or pomace and waste water called OMWW or vegetable water. The OMWW's characteristics and compositions vary with the different extraction techniques and these are specified in Tables 5, 7 and 8. However, all vegetable waters contain a high level organic polluting load and cannot be disposed in municipal waste sewage before treatment.

Below are the BAT concerned with reducing the emission load of pollutants in the wastewater discharges by using one or a combination of the following techniques/waste water treatment systems:

TABLE 15: BAT for the management of OMWW

Technique	**Applicability**

Standard good practice techniques to ensure good storage of raw liquid materials (inspection of tanks, overfill protection …)	Generally applicable
Standard pollution control methods (screening, filtration…)	Generally applicable, though only as first step and waste water needs to be further treated because of its high organic and phytotoxic contents
Biological treatment systems (aerobic/anaerobic digestion, bio-filtration…)	Generally applicable though subject to variability in volumes, and available human and financial resources
Chemical treatment systems (coagulation, flocculation…)	Generally applicable though subject to variability in volumes, and available human and financial resources
Thermal treatment systems (evaporation)	Generally applicable though subject to variability in volumes, and available human and financial resources
Valorization of vegetable waste through appropriate use on-site or in other fields	Generally applicable. They require the necessary know-how and finance
Discharge to municipal waste water treatment plants	Generally applicable, but only after further treatment to render the vegetable water of acceptable standards for the sewage system
Switch to/combine with two-phase or two-and-a-half phase system	Generally applicable, but requires finance and training

7.3.2 Solid waste/pomace

All extraction techniques produce a solid-like waste called pomace or cake along with vegetable water, with the exception of the two-phase and two-and-a-half phase systems which produce only a more liquid/wet (sludge-like) pomace with no, or minimal vegetable water stream. This translates into pre-treatment steps to render the wet pomace into an easier to manage, condensed waste. However, depending on the specific characteristics of the produced pomace, as listed in TABLE 5 and TABLE 6, one or a combination of the following BAT could be used to manage and valorize the pomace:

TABLE 16: BAT for the management of pomace

Technique	Applicability
Valorization of solid waste through appropriate use on-site or in other fields	Generally applicable though subject to variable volumes and economic viability
Biological treatment systems, such as composting or anaerobic digestion	Generally applicable though subject to variability in volumes, and available human and financial resources
Introduce de-stoning of the olive prior to malaxation	Generally applicable, but requires finance and training producing eventually a separate, parallel stream for the stones
Thermal treatment systems (combustion, pyrolysis, etc…)	Generally applicable though subject to variability in volumes, and available human and financial resources

8. BAT CONCLUSIONS

Having charted all BAT for all the different elements in the olive oil milling systems, and as can be concluded from the tables of chapter 6, there are many available techniques and methods to eliminate/reduce the pollution load resulting from the olive oil extraction industry. Major improvement can be seen in the reduction or total elimination of vegetable waters with the adoption of the two-phase or two-and-a-half phase systems. However, this transfers part of the problem from the vegetable water to a much more fluid solid waste, the wet pomace. This is because treatment of wet pomace is more complex than the pomace of the three-phase system precisely because of its high moisture content, reaching up to 70%. With the adoption of an additional drying step, this problem can be easily surmounted, especially if the additional energy and water used for this step can be recycled within the system. The addition of a de-stoning step can further enhance the quality of oil and facilitate treatment of effluents and as such reduce the environmental impacts of the process.

In this section of the report, we draw on the above charted tables to create new ones that will help in making the decision of the best system to adopt in cases within the MENA region. As such, in the below tables, the main parameters for each extraction system is presented along a scale of complex/high (difficult), medium and low (easy). This will further assist in determining which of these systems is more applicable and beneficial for the specific site/case. It is important to note here that as the same category can be both negative and positive for different parameters (for example, 'high' may be positive for ‘applicability’ but negative for ‘environmental impact’), a coloring scheme is adopted to overcome this obstacle. **Red** will be used for *negative* effect, **yellow** will be used for *medium* effect and **green** for *positive* effect (see TABLE 17).

In the environmental parameter, the impacts are calculated according to their significance, nature, magnitude, extent, duration, timing, reversibility and likelihood of occurrence. All these elements have been embedded in the environmental analysis (see

TABLE 19). Systems were labelled '**high**' when they scored high in most of the categories mentioned above. They scored an overall '**medium**' when they exhibited varying results across categories. Finally, they were labelled '**low**', if they scored a majority of no to minimal across the various categories mentioned (see Table 19).

For applicability, '**high**' refers to a system that can be easily implemented on an *industrial* scale. '**Medium**' are the systems that have moved from the pilot mode to industrial scale but have *not been fully endorsed or funded* at a national level. Finally, '**low**' applicability is for systems that are still in a *laboratory or pilot* testing phase (see

TABLE 18).

In operational terms, '**high**' refers to systems that require sophisticated or *specially trained* personnel, *specific* machines and/or *large* physical space. '**Medium**' level of operationality means that these systems can be implemented by *re-purposing* of spaces and/or machines and *re-training* of personnel. In case of '**low**' operationality, systems are *easy* to implement and do *not* require any intensive training nor a major change in the machinery and/or *additional* physical space (see

TABLE 18).

Similarly, in economic terms, a '**high**' system requires *high* capital and/or operational costs as well as *high* environmental cost (i.e. high cost mitigation plans). With '**medium**', the system necessitates *medium* level of operational/capital cost and its environmental degradation cost is *not high.* '**Low**' system requires *very little to no* capital and/or operational costs and its environmental degradation cost is *minimal or non-existent* (see

TABLE 18).

TABLE 17: Coloring scale of evaluation

	Environmental Impacts	Applicability	Operational	Economics
Positive	Low/easy	Complex/High	Low/easy	Low/easy
Medium	Medium	Medium	Medium	Medium
Negative	Complex/High	Low/easy	Complex/High	Complex/High

TABLE 18: Scale of evaluation according to BAT parameters

	Environmental Impacts	Applicability	Operational	Economics
Complex/ High	Scores a majority of high across environmental categories (minimum of 3)	Can be easily implemented on an *industrial* scale	Requires *specially trained* personnel, *specific* machines and/or space	Requires *high* capital and/or operational costs as well as *high* environmental cost (mitigation)

Medium	Scores medium in all categories or exhibits varying results across categories	Moved from pilot testing to industrial scale but have *not been_fully endorsed or funded* on a national level	Can be implemented by *re-purposing* of spaces and/or machines and *re-training* of personnel	Necessitates *medium* level of operational/capital cost and its environmental degradation cost is *not high.*
Easy/ Low	Scores a majority of no to minimal across categories (minimum of 3)	still in a *laboratory or pilot* testing phase	E*asy* to implement without any intensive training nor a major change in the machinery and/or space	*Very little to no* capital and/or operational costs and environmental degradation cost is *minimal, if any*

TABLE 19: Parameters considered in the study of environmental impacts

Criteria	Classification	Environmental Impacts
Significance	Low	Results in no substantial adverse changes in environmental conditions
	Medium	Substantial adverse change to existing environmental conditions Can be mitigated to less-than-significant levels by implementation of proposed potentially feasible mitigation measures or by the selection of an environmentally superior project alternative
	High	Substantial adverse change to existing environmental conditions. Cannot be fully mitigated by implementation of all feasible mitigation measures.
Nature	Positive	The proposed activity offers benefits for the overall project
	Negative	Impacts having minimal to major negative influence
Magnitude	Low	High potential to mitigate negative impacts on the physical, biological or human environment to the level of insignificant effects Disturbance of degraded areas with little conservation value. Minor changes in species occurrence or variety. Simple mitigation measures may be needed to minimize impacts.
	Moderate	Medium range (beyond project site boundary but restricted to local area) Medium term (reversible over time, duration of operational phase) Potential to mitigate negative impacts on physical, biological or human environment. However, the implementation of mitigation measures may still not prevent some negative effects.
	High	Largely irreversible impacts on the physical, biological or human environment Has a massive impact on the surrounding
Extent	Local	Limited to the project area
	Global	Extended beyond the project area National impact affecting resources on a national scale

		Contribute to one of the global environmental problems (climate change, ozone depletion, etc…)
Duration		During construction or operation
Timing	Short	Activities and their related impacts are characterized by a short duration of effect
	Medium	Activities and their related impacts are characterized by a medium duration of effect
	Long term	Activities and their related impacts are characterized by a long duration of effect
Reversibility	Reversible	Impacts may be reversible
	Irreversible	Impacts may be irreversible
Likelihood of occurrence	Low	The classified impact is unlikely to occur under normal operating conditions
	Medium	The classified impact may possibly occur
	High	The classified impact is likely to occur under normal conditions

Based on the above, BAT assessment was conducted for the different extraction techniques and the various mitigation systems and techniques available to manage wastes and valorize them. The results are shown in the tables below.

TABLE 20: Comparison between the various milling systems

	Environmental Impacts	Applicability	Operational	Economics
Traditional Press	High	High	Low	Low
Three-phase system	High	High	High *	High*
Two-phase system	Medium	Medium	High* Medium**	High* Medium**
Two-and-a-half phase system	Medium	Medium	High* Medium**	High* Medium
De-stoning system	Medium	High	Low	Low

With * referring to a switch from traditional press to three-phase system and ** referring to a switch from three-phase to two-phase system.

As can be easily concluded from the table above, the three–phase system should be dropped from the analysis as it scores negative on three out of four categories (this is especially correct if it is in consideration of a move away from the traditional press system, rampant in the study region). The traditional system can also be dropped even if it scored well on three categories out of four. Such decision is made because traditional mills score a negative high on the parameter of prime importance to this report, that of the environmental impacts. The two and the two-and-a-half systems have equal high scoring in terms of benefits and applicability, especially if the move is made from an existing three-phase system. Financial, physical and staffing issues arise if the move is made from a traditional mill. These parameters need to be then individually examined to assess the feasibility of such a switch. Finally, de-stoning scores the highest on all categories. As it is a technique that can be added to any of the extraction systems, the table above provides justification to apply de-stoning to any adopted system of extraction.

With environmental impact of prime importance for this study, the conclusions that can be drawn from this table is that de-stoning, two-phase and two-and-a-half-phase systems should be adopted as BAT for the best possible scenario.

Additionally, as de-stoning can be added to another system as a preliminary step in the extraction process, it is safe to conclude that a combination of de-stoning and two-phase or two-and-a-half-phase systems would provide the best option.

The above section dealt with the systems used for extraction and which of these provides the best applicability (operationally as well as economically) and efficiency, all the while producing the least impact on the environment. However, no holistic conclusion should be drawn in isolation of waste treatment options. Therefore, in the coming paragraphs, the focus will be on the treatment and valorization of the different techniques suggested to treat the resulting by-products.

Table 21 below provides a summary of all the applicable techniques discussed in chapters 2 and 4. The same coloring scheme is used to identify the best techniques along the parameters shown in the first row of the table.

TABLE 21: Summary of applicable techniques

	Pre-treatement needed	Energy/ water consumption	By-products	By-products valorisation	Challenges
Olive Mill Waste water					
Land application	No	Minimal	None	None	Minimal. Right dose/time/manner should be established
Percolation / Sinolea	No	High	Wet pomace	No, unless further treated	Low oil yield, Requires medium technical and operational capacities
Evaporation (lagooning)	No	Low	Solid	No	-Requires space -Fear of leaking if lagoon not properly sealed -Insects and odor nuisance
Evaporation (forced/ vaccum)	Yes	Medium	Distillate and solid waste	-Distillate needs further treatment -Solid waste can be used as fertilizer, animal fodder or de-oiled for heat	-Requires space and technical know-how -distillate requires further treatment before disposal or re-use.
Pomace					
Composting (aerobic)	Not essential	Low	Sludge	Fertilizer	Minimal. Right aeration rate/dose/time/manner should be established
Anaerobic digestion	Yes	Low	Sludge, biogas	Fertilizer, heat	Pre-treatment required
Drying	No	High	Dry pomace	De-oiled with hexane to be used as fertilizer or energy production	-High energy demand -Air pollution -can't be used with two-phase wet pomace
Combustion	Yes	High	Heat, Ashes	-Ashes cannot be re-used. -Energy production	-High energy demand -Air pollution

As can be detected from this table, the techniques that stand out as most applicable and efficient are land application, composting, anaerobic digestion and lagooning. It is important to note here that for all these treatment methods, it is essential to properly profile the effluents produced in the system and accordingly identify the right dose, time and manner of application of the treatment technique so that they achieve their best potential.

TABLE 22 below lists the various techniques to treat the effluents of the different systems (pomace, wet pomace and vegetable water) according to the parameters specified in TABLE 9 and adopting the same category and color scale of TABLE 17 and
TABLE 18.

TABLE 22: Techniques to treat the various effluents of the different milling systems

	Environmental impacts	Applicability	Operational	Economics
Olive Mill Wastewater				
Land application	Low	High	Low	Low
Natural evaporation (lagooning)	Low	High	Low	Low
Evaporation (forced/vaccum)	Low	Medium	Medium	Medium
Pomace				
Composting (aerobic)	Low	High	Low	Low
Anaerobic digestion	Low	High	Medium	Medium
Drying	Medium	Medium	Medium	Low
Combustion	High	Medium	Medium	High

In line with the above conclusions, in TABLE 22 we find that land application, composting, anaerobic digestion and lagooning provide the most applicable and environmentally friendly techniques that should be used alongside the best extraction processes (de-stoning and/or two-phase or two-and-a-half phase) to provide economically, operationally and environmentally acceptable systems. When valorization of the by-products is added to the equation; direct land application, composting and anaerobic digestion stand out before evaporation.

Considering the olive oil milling profile of the MENA region, geological variations and economical profiles, in light of the findings highlighted and analysis conducted in this report, several conclusions can be drawn as to what systems and which treatment methods are needed for the region.

The current profile of the olive oil mills in the region and related elements can be summarised as follows: a prevalence of traditional mills, followed by three-phase system mills; sporadic scattering of small to medium sized mills; long dry seasons; a wide variation of geological and topographical formation (with a prevalence of limestone and equally absorbent and fertile soils); abundance of water supply especially during rainy season, availability of land, fairly cheap labour force as well as relatively lenient environmental laws and/or weakness in their implementation.

Based on such profile and according to the analysis conducted, the following recommendations can be made:

Traditional and three-phase mills exhibited the highest pollution load, coupled with lower oil yield levels. Therefore, switching to less polluting with higher yield levels' practices is advised, and these are two-phase or two-and-a-half phase system mills. However, economic capacity needs to be taken into account especially in the case of moving away from traditional mills (widely used in locations such as Lebanon, Syria, Libya and Palestine) to two or two-and-a-half phase systems, which require high capital investment. Having said that, as three-phase mills are more widely used in the MENA region since the 1990s, the switch in many locations (namely Spain, Italy, Morocco, Tunisia, Israel, Egypt and so on) to two-phase or two-and-a-half phase system mills is less economically demanding. In addition, as these latter systems are proving to be highly regarded in the olive oil industry with the increase in environmental awareness internationally, they are attracting governmental appeal now more. In fact, governments in Tunisia, Morocco, Algeria and Jordan have started or have already implemented switching to two and two-and-a-half phase mills. However, for the mills to adopt those systems, there is need for some financial support and the use of economic instruments/incentives from the government similarly to what happened in Spain. Moreover, the shifting to the two-phase system has to be complemented with solutions to treat and valorize the wet pomace produced by this technology and complete the circular economy cycle.

In this report, the addition of a de-stoning step to the switching of the operating mechanism to a two or a two-and-a-half phase system is highly advisable. As described before, this uncostly and easy to implement technique will not only ensure higher yield and better oil quality than without it, it will also make the resultant effluent less toxic and easier to manage. In addition, the stones, as previously advanced, provide a primary high calorific source for heat and energy. This also provides a direct incentive for a circular economy type of industry. In line with this thinking, and as elaborately advanced in previous chapters, the report focuses on recycling of heat and water, and emphasis is placed on how important it is for such practices to become an integral part of operating mills. Adoption of closed heating/cooling systems needs to be followed in whichever milling system is in use. This will not only cancel or minimise the loss of heat and/or water but will also inject water and heat back into the system in a recycling mode. This will lead to, not only reducing the total cost of the operation but also, of course, reducing the environmental mitigation cost of the overall operation.

There is no zero-cost solution for the treatment and valorization of olive mill wastes. It is understood that small and medium size mills will be looking for low cost solutions especially with the relatively low prices of oil internationally; however, the external cost of environmental degradation emanating from the improper disposal of olive mill waste should also be accounted for. To reduce the cost it is advisable that mills form cooperatives and apply treatment or valorization techniques together to create economies of scale and reduce their costs.

As previously iterated, the decision regarding which operating system to adopt is the most important and influential factor contributing to the type and nature of the resulting affluent. Once the operating system is chosen (adoption of two and/or two-and-a-half phase system coupled with de-stoning step) and practices (closed heat and water systems) within it are adopted, the choice of the treatment method can be done. In this report, several alternatives have been identified to provide the optimal management of OMW. However, it is important to note here that due attention to specificities of each country and locations of mills is needed as well as varying factors (such as agricultural practices and the nature of the olive fruit, climate and topography, water bodies details and so on) to be taken into account that can affect the choice of the method chosen to treat resulting effluents. Controlling for these particularities, the report suggests that OMW should be treated via composting, anaerobic digestion or lagooning. These options provided the optimum economic, environmental and socially viable solution for treatment of OMW. While in low land value areas, lagooning can be the best option, aerobic or anaerobic digestion may prove more economically viable in high-cost land locations. When possible, direct land application of vegetable water as soil enrichers, fertilizers or pesticides should be used in every possible scenario, as it improves the agricultural profile and output and is economically less demanding.

Besides technical solutions, there should be progress throughout the region on:

- Legal frameworks governing the licensing, siting and application of different technologies and treatment methods. Tunisia, Lebanon, Israel, Algeria, and Syria among others have legislation for the land application of OMWW, for example, and this can be improved and expanded to other countries (e.g. Libya and Palestine). Moreover, guidelines for the establishment and operation of olive mills should also be put in place in some countries (Libya, Algeria).
- Proper enforcement of legislation.
- Economic incentives or disincentives that would encourage the use of BAT and BEP and penalize environmental polluters. An example is the FODEP (Fonds National de Maîtrise d’Energie) in Tunisia that helped finance 20% of depollution projects in grants and 50% in loans with 3 years of grace period, repayment over 10 years and exemption from VAT and customs fees.
- The formation of cooperatives to seek and implement common solutions and treatment methods to create economies of scale and mutual benefits (Hamdan, 2019).
- Training of olive mill owners and staff as well as other stakeholders on the proper management of olive mill waste.

9. ANNEX

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