SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

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 THE OLIVE OIL PRODUCTION.

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This Project is funded by the European Union

SWIM and Horizon 2020 SM

SWIM-H2020 SM in a Snapshot

Profile

The **SWIM-H2020 SM Project**, funded by the European Union, aims to contribute to reduced marine pollution and a sustainable use of scarce water resources in the Mediterranean Region with emphasis on the **countries of North Africa and the Middle East (Algeria, Egypt, Israel, Jordan, Lebanon, [Libya], Morocco, Palestine, [Syria] and Tunisia).**

Components of the Project

The Project is the continuation and merging of two successful previous EU-funded service contracts, Horizon 2020 Capacity Building/Mediterranean Environment Programme (H2020 CB/MEP) (2009-2014) and the Sustainable Water Integrated Management Support Mechanism (SWIM SM) (2010-2015).

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SWIM-H2020 SM

The Project is to:

- Provide tailored and targeted technical assistance at national level based on partners' requests through an Expert Facility;
- Organize regional (or sub-regional) peer-to-peer seminars and webinars;
- Conduct on-site training courses and study tours;
- Capitalize on the lessons learnt, good practices and success stories;
- Support logistically and technically the Horizon 2020 Initiative's Steering Group & Sub Groups and the Meetings of the Union for the Mediterranean's Water Experts Group.

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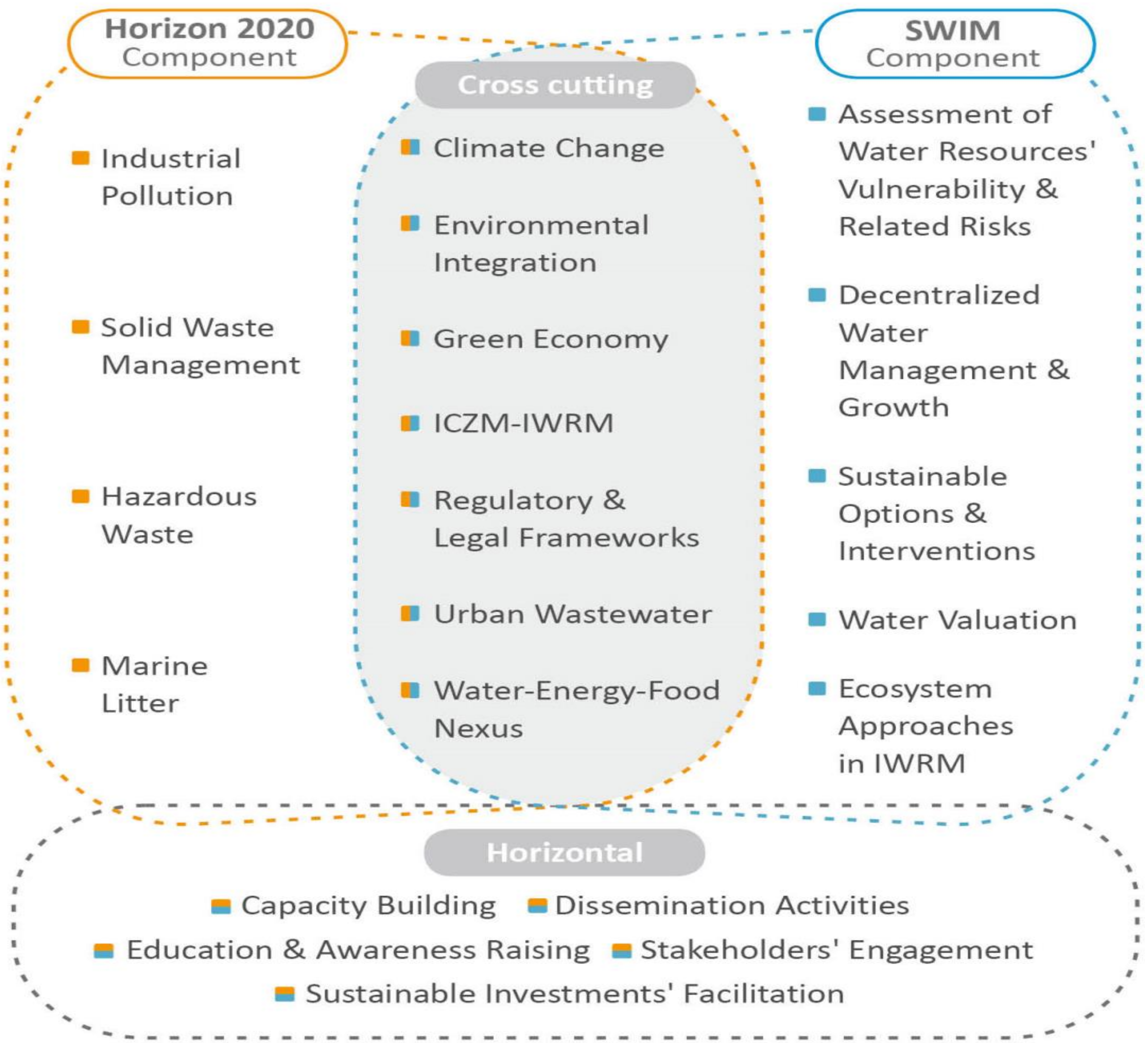
SWIM-H2020 SM Expected Results

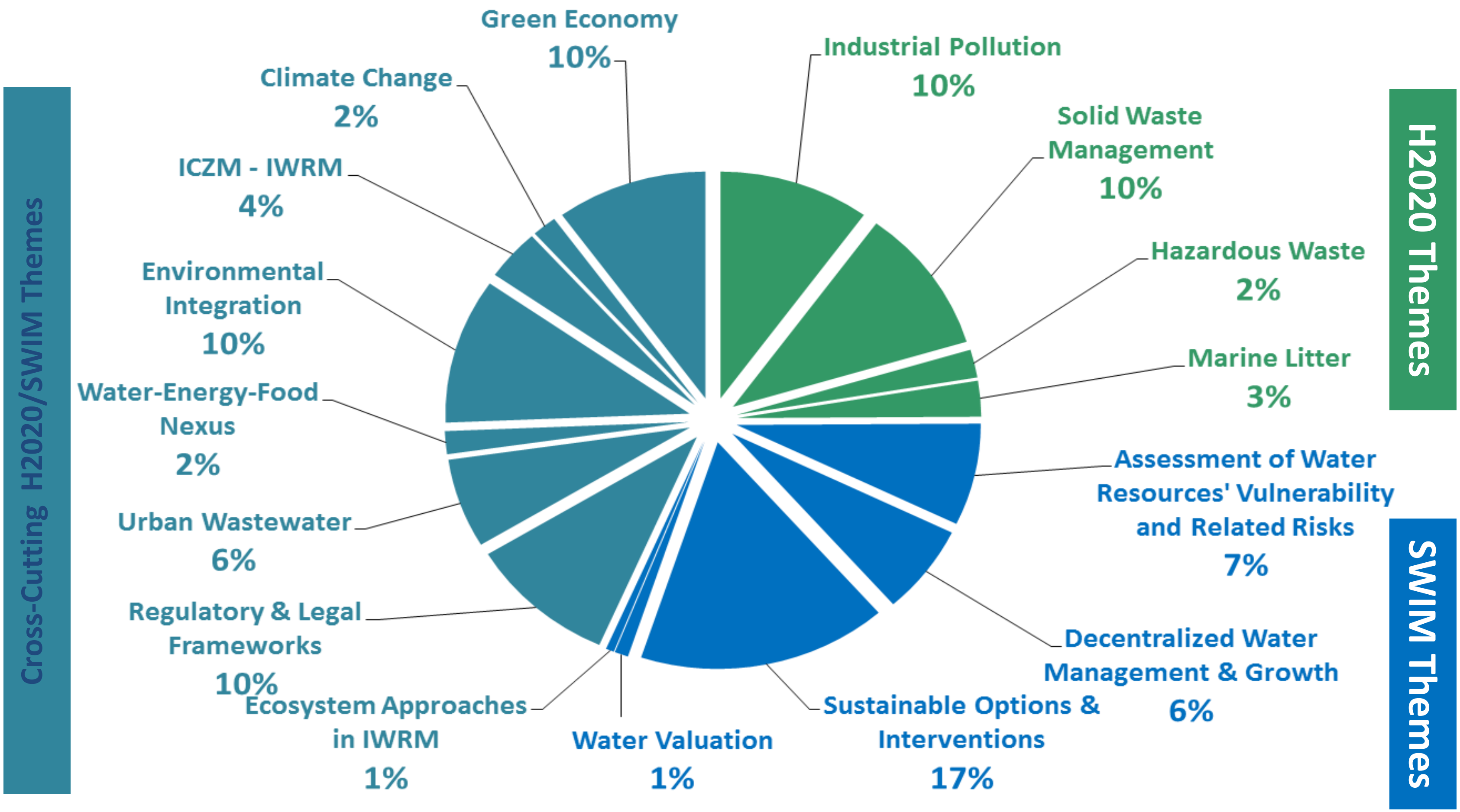
In order to Achieve:

- Positive changes in the design and implementation of the relevant national institutional, policy and regulatory frameworks;
- Enhancement of partner countries' capacity to promote investment and business opportunities for properly managing municipal waste, industrial emissions and waste water;
- Facilitation of access to finance for selected sustainable investment projects;
- Strengthening of regional coherence and cooperation in approaches to marine pollution prevention and control, and sustainable water management;
- Identification, testing and sharing of best practices and success stories;
- Use of research results in policy making – enhancement of more sustainable practices.

SWIM-H2020 SM Themes



Project themes



SWIM-H2020 SM Cooperation

Framework of Cooperation

The project is based on synergies, which are further developed and supported through:

- **The SWIM-H2020 SM Focal Points (FPs)** in the Ministries in charge of Water and Environment of the Partner Countries, which also constitute the SWIM-H2020 SM Steering Committee.
- **Regional bodies forming the Institutional Partners** of the Project, namely:
  - the **Union for the Mediterranean (UfM**), assisting on issues linked with the draft Strategy for Water in the Mediterranean, the Water Strategy in the Western Mediterranean (5+5), projects and investments related with Mediterranean pollution Hot Spots.
  - the **Mediterranean Action Plan of UNEP (UNEP/MAP**), supporting activities related to the Land Based Sources (LBS), the Hazardous Wastes and Integrated Coastal Zone Management (ICZM) Protocols of the Barcelona Convention as well as the revised National Action Plans (NAPs).
- **Relevant EU Institutions** (including DG ENV, NEAR, Research, MARE, etc.) such as the European Investment Bank (EIB) which coordinates the Mediterranean Hot Spots Investment Programme II (MeHSIP II) and **Agencies** such as the European Environment Agency (EEA), which coordinates the Shared Environmental Information System (SEIS) South.
- **Other Regional Initiatives and Projects** (SwitchMed, CLIMA South, etc.).

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SWIM-H2020 SM Identity

Partner countries:
Algeria, Egypt, Israel, Jordan, Lebanon, [Libya], Morocco, Palestine, [Syria], Tunisia
Participation of Albania, Bosnia Herzegovina, Mauritania, Montenegro and Turkey in regional activities will be considered.

Contracting Authority:
Directorate-General for Neighborhood and Enlargement Negotiations (DG NEAR)

SWIM-H2020 SM Team:
Mr. Stavros Damianidis, Project Director
Prof. Michael Scoullos, Team Leader
Mrs. Suzan Taha, Water Expert
Mr. Ismail Anis, Environment Expert

Duration:
36 months (2016-2019)

Budget:
6.286.000 Euros

SWIM-H2020 SM Consortium

LDK Consultants S.A. (Leader)
LDK Consultants Europe S.A.

Arab Countries Water Utilities Association (ACWUA)

Arab Network for Environment and Development "RAED“

Association of Cities & Regions for Recycling and Sustainable Resource Management (ACR+)

Catalan Waste Agency (hosting institution of Regional Activity Centre for Sustainable Consumption and Production (SCP/RAC))

EEIG UT – SEMIDE

GLOBE ONE LTD

Haskoning DHV Nederland B.V.

Mediterranean Information Office for Environment, Culture and Sustainable Development (MIO - ECSDE)

Milieu Ltd

National and Kapodistrian University of Athens (UoA)

Umweltbundesamt GmbH

WS Atkins International Ltd

SWIM-H2020 SM in Numbers

The Project in Numbers

1	Support Mechanism
2	Components (SWIM and Horizon 2020)
8	Partner Countries
19	Major Synergies
14	Consortium Partners
15	Members of SWIM-H2020 SM Core Team
36	Months (2016-2019)
6.286.000	Euros Budget
21	Themes
100	Activities
23	Annual Meetings
11	Categories of Stakeholders involved
1	Internet Site
2	Social Media Pages (LinkedIn, Facebook)

1 GOAL: TO SUCCEED!

Best Practices of the Olive Oil Production Sector for Waste Minimization, Water and Energy Consumption and Valorization of the Sub-products of the Olive Oil Production

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Outline

- **Olive oil production profile in the region**
- **Olive oil production and the environment**
- **Current processes and techniques**
    - Traditional Press
    - Continuous Three-Phase
    - Continuous Two-Phase
    - Continuous Two-Phase and-a-Half
    - Stone Removing
    - Percolation
    - Chemical Separation
    - Electrophoresis
    - New emerging techniques

Outline

- **Olive Oil Wastes: characteristics and emissions**
- **BAT**
  - Olive oil extraction
  - Pomace thermal processing
  - Vegetable water
    - Biological treatment
    - Thermal treatment
    - Physico-chemical/ oxidation treatment
    - Direct application as bio/herbicide
  - Reduction of water consumption
  - Reduction of energy consumption
- **Case studies**
- **Conclusions**

Olive Oil Production in the world

- ¾ of global olive oil production is concentrated in the European Mediterranean countries.
- Spain leads, followed by Italy and Greece.
- The majority of the world's olive oil remaining production ($500X10^3$ tons/2017) comes from the MENA region.
- New emerging countries like New Zealand, USA, Chile, Argentina and Australia

Country	Average 1993-2014 (Tonnes)
Spain	1,059,194
Italy	557,574
Greece	344,615
Tunisia	159,990
Syria	140,466
Turkey	128,168
Morocco	77,145

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Olive Oil Production Peculiarity

Huge year-to-year swings in the production because:

- Characteristic alternate bearing pattern of olive tree.
- Climate and rainfall.
- Geological/ geographical soil characteristics.
- Cultural practices.

Olive Oil Production Structure

- **OO is a Mediterranean product of great importance from a production and consumption point of view.**
- **OO production structure is highly complex and varied depending on:**
  - Variations in regional production.
  - Market internationalization.
  - Diversity of producer organisations:
    - Producer organisations exist in countries with a wide spectrum of infrastructural and developmental frames.
    - Producer organisations exist in a fragmented sector due to variations in size between and within countries.
    - Production systems vary dramatically between and within countries.

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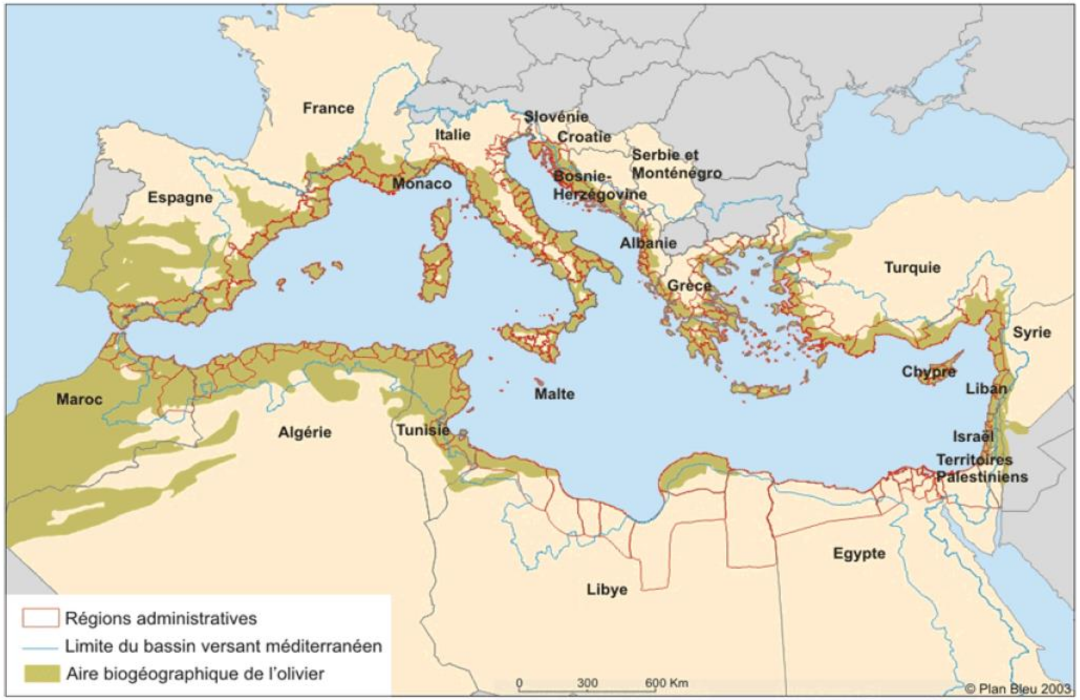
Area of study: the MENA region

MENA stands for Middle East and North Africa and conventionally includes:

Syria, Lebanon, Jordan, Palestine, Israel, Egypt, Libya, Tunisia, Algeria and Morocco



Source : Gaussen & De Philippis - FAO

Olive Oil Production in MENA Region (1000 tons) 2013-2018

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)

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Olive Oil Production/Country in MENA

Country	Number of mills	Size	System used	Number of olive trees (million)	Olive Oil Production (Tons/Year)	OMWW (m^3/ Year)	Pomace (Tons/ Year)
Jordan	130	Small & medium	3 & 2-phase	20	20 000	200 000	
Morocco	15,842	Large, medium & small	Mostly traditional. 3 & 2-phase		170 000		
Palestine	274	Small & medium	Mostly traditional	11.5	19 500		
Tunisia	1,707		Traditional& continuous (2 &3-phase)		100 000	700 000	450 000
Syria	1,066	Small & medium	Traditional & continuous (2 &3-phase)		110 000		

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Olive Oil Production/Country in MENA (continued)

Country	Number of mills	Size	System used	Number of olive trees (million)	Olive Oil Production (Tons/Year)	OMWW (m^3/ Year)	Pomace (Tons/ Year)
Egypt	73	Small & medium	Mostly continuous (2 & 3-phase)		20 000		
Algeria					63 000		
Lebanon	492		Mostly traditional		25 000	280 000	84 000
Libya					16 000		
Israel	130		Continuous (Mostly 3-phase, & few 2-phase)		15 000		

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Trade

- Production value of OO in 2017 in MENA was $1.8 billion (global production value is around $11 billion mostly in the EU).
- Exports from MENA in 2017 were at $1 billion (compared with $2 billion from the EU).
- Production is constantly growing and has shifted from non-virgin to virgin oil.
- Growth in demand for OO especially with increase in number of health

  conscious consumers.
- Record of 5.3% compound annual growth rate by 2021 (the forecast was for 3.8% global average).

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Production, Export and Import of Olive Oil (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)

Trade: Distribution in MENA region

- 86% of the OO consumed in the region is bought in modern distribution channels such as hypermarkets, supermarkets and discount stores.
- Hypermarkets are consumers' preferred place of purchase for virgin olive oil, accounting for 40% of all the OO consumed.
- Supermarkets are the choice for OO purchase (amounting to 39%).
- Around 1/5th of OO purchases are made in discount stores.
- Exception arises. For example, majority of OO produced in Lebanon is sold in bulks in olive mills.

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Trade: Competition

Production

- In MENA region, Tunisia takes the first position, followed by Morocco and Algeria

Consumption

- In the MENA region, Turkey followed by Morocco take the lead.

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Legislative Framework for Olive Oil Production

- **International agreements signed by MENA countries related to the protection of different environmental media from sources of pollution:**
  - Decision No DEC-18/S.ex.27-V/2016 "Revising the trade standard applying to olive oils and pomace oils- July, 16, 2016-Tunisia.
  - 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.
- **National legislative texts include:**
  - Article 16 of the Agriculture Law no 44/2002 (**Jordan):** Instructions for the licensing and operation of olive presses for 2012. Law no. 13/2015 for the control of olive mill operations.
  - Ministry of Environment (MoE) Decision No. 100/1 dated July 2010 (Lebanon): Implementation of the Guidance Note for the olive oil industry in Lebanon and the resulting environmental pollution.
  - MoE Decision No. 101/1, July 2010 (Lebanon): Environmental conditions for licensing the establishment and/or operation of olive mills.
  - MoE Decision No. 102/1, July 2010 (Lebanon): Conditions for reusing vegetable water in irrigation.

Legislative Framework for Olive Oil Production

- **National legislative texts include:**
  - Ministry of Local Administration and Environment Decision No. 119/N dated 24/9/2007 (Syria): Environmental conditions for the licensing of olive mills.
  - Ministry of Agriculture and Agrarian Reform Decision No. 190/T dated 5/9/2007 (Syria): Mechanism for the collection and distribution of vegetable water on agricultural lands.
  - Ministry of Agriculture and Agrarian Reform Decision No. 1214 dated 19/7/2007 (Syria): Environmental conditions for olive mills.
  - Ministry of Agriculture Decree No. 2013-1308 of February 26, 2013, (Tunisia): Conditions and procedures for managing vegetable water and their use in agricultural fields.
  - Ministry of Industry Decree No. 2008-2036 of May 26, 2008,, Energy and Small and Medium Enterprises (Tunisia): Characteristics and conditions for packaging, packaging and labelling of olive oils and olive-pomace oils.
  - 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.

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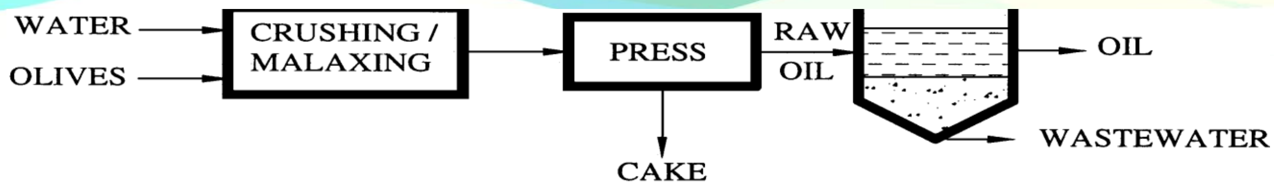
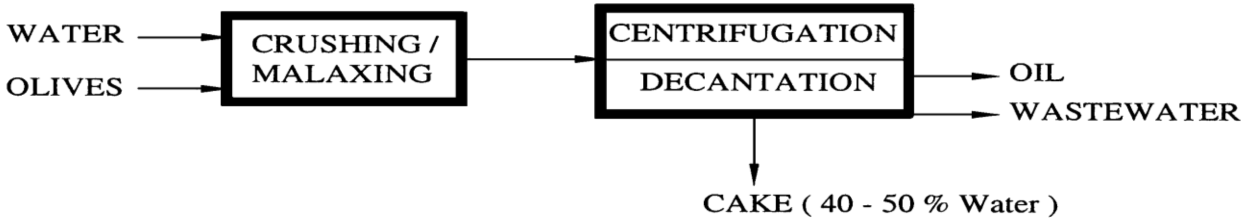
Olive Oil Sector and the Environment

- Olive Mill Waste (OMW) is highly phytotoxic and have negative impact on land and water.
- Annual world OMW is estimated to be around 30 million m^3.
- Amount and physicochemical characteristics of OMW depend on oil extraction system, processed fruits and operating conditions.
- **OMW can lead to**
  - Soil contamination.
  - Ground water contamination.
  - Surface water contamination.
  - Air pollution.
  - Noise pollution.
  - Public Health and Safety issues.

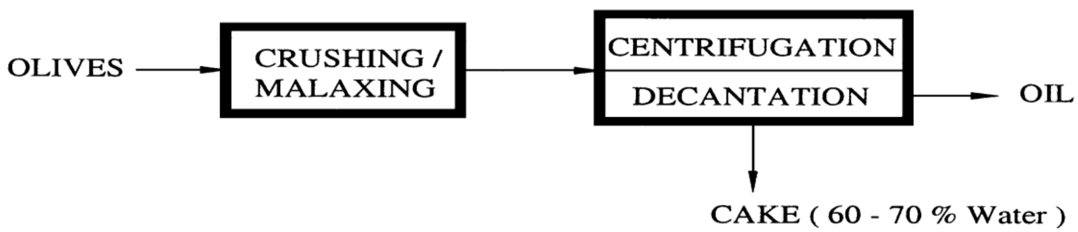
Typical Olive Oil Extraction Processes



Press process (Batch)



3 - Phase process (Continuous)



2 - Phase process (Continuous)

Stone removing, percolation, chemical separation and electrophoresis, as well as pilot scale techniques such as US, MW and PEF, are additional steps and ways to extract oil from the fruit.

Olive Oil Production Inputs and Outputs

Inputs	Process	Outputs
Harvested olive	Mill Reception	Raw Olives (dirt, earthly waste) Packaging Material (eg. Nylon bags)
Raw Olives (dirt & Earthly Waste) + Electricity	Leaf Stripping (air blower)	Stripped Olives Earthly Waste (leaves/ stems)
Stripped Olives + Water	Olive Washing (washing machine)	Washed Olives Olive Washing Wastewater
Electricity + washed Olives	Olive Grinding (stone mill/grinder)	Non-homogenized Paste Noise (could exceed 90 dBA)
Paste+ Electricity+ Water + Heat (continuous syst. only)	Paste Malaxing	Homogenized Paste
Hom. Paste + Water + Energy	Oil Extraction (Hydraulic Press / horizontal Decanter)	Olive Oil with impurities Vegetation water (pH, BOD, COD, TSS, Phenols, residual oil Fe, P, K) Pomace (residual oil, humidity, P, K) Noise
Rich oil + Water + Electricity	Oil Purification (natural decanting/ vertical Centrifuge)	Pure olive oil Oil rinsing water (BOD, COD, TSS, Phenols, oil) & Noise
Purified Olive Oil	Oil Bottling & Storage	Packaged Olive Oil (Bottled) Damaged Packages/Spilled oil

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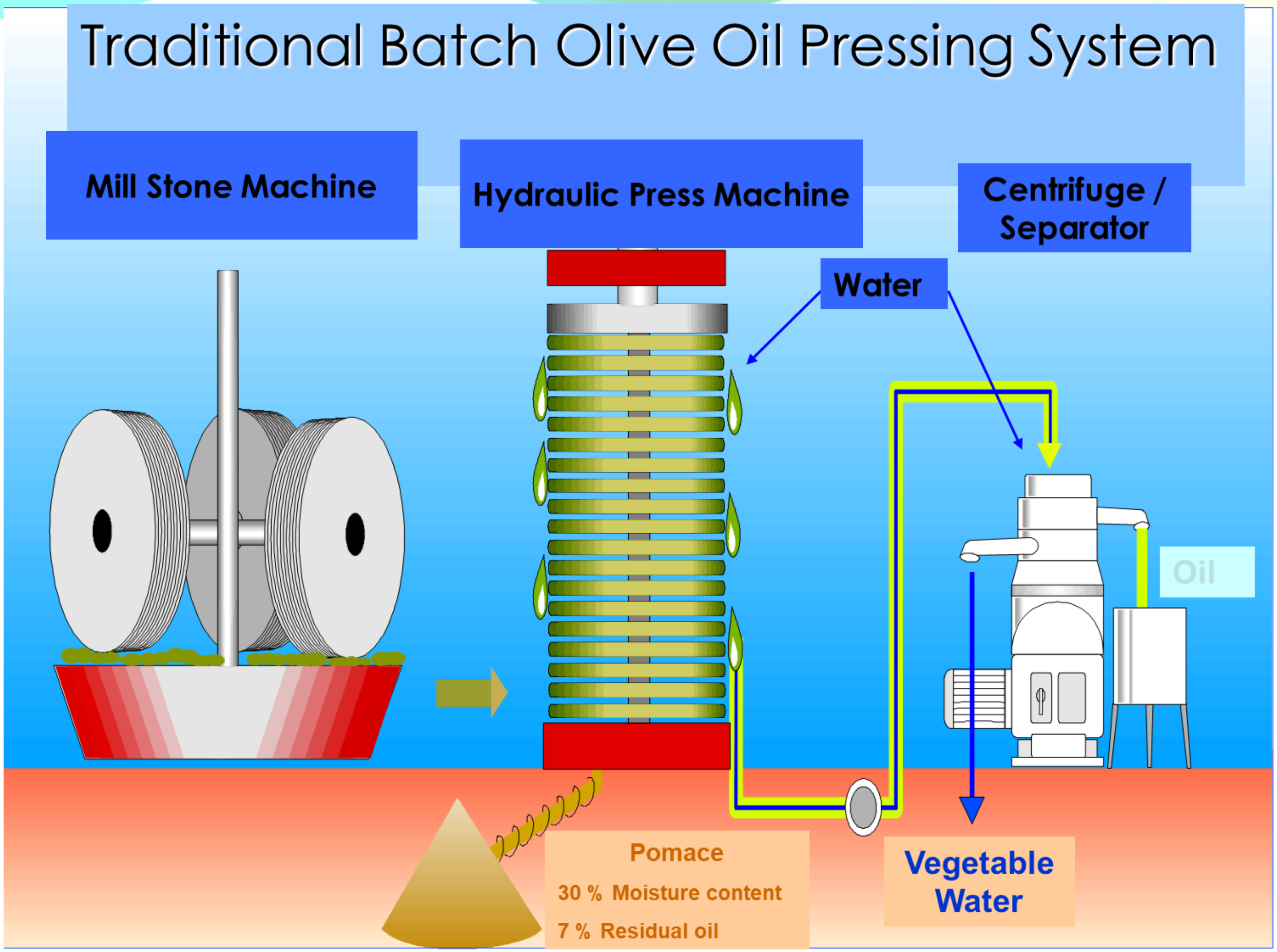
Traditional Press System

- It is the oldest method.
- It is based on extraction by pressure.
- Olives are cleaned, rinsed and stored then milled in stone mills.
- Remaining solid waste is laid on pressing mats (piled in a wagon, rotated by a central axis creating a charge).
- Charge is pressed by hydraulic press producing OO and vegetable water.
- Oil is separated by natural decantation or settling in tanks.
- Oil is then purified in a centrifuge.

Traditional Press System



Traditional Press System

Advantages:

- Low manufacturing cost.
- Short storage of olive fruit.
- High quality oil.

Disadvantages:

- High number of staff.
- Lower yield of oil compared with other techniques.

Continuous Three-Phase System

- Introduced in 1970s.
- Replaced traditional press with horizontal centrifuges, or ‘decanters’.
- Olives are milled in hammers or disks.
- The resulting paste is sent by variable speed pumps to a horizontal centrifuge.
- The centrifuge separate the paste into three phases:
  - Spent olive (or pomace and can be treated to extract olive-kernel oil).
  - Oil.
  - Vegetable water.

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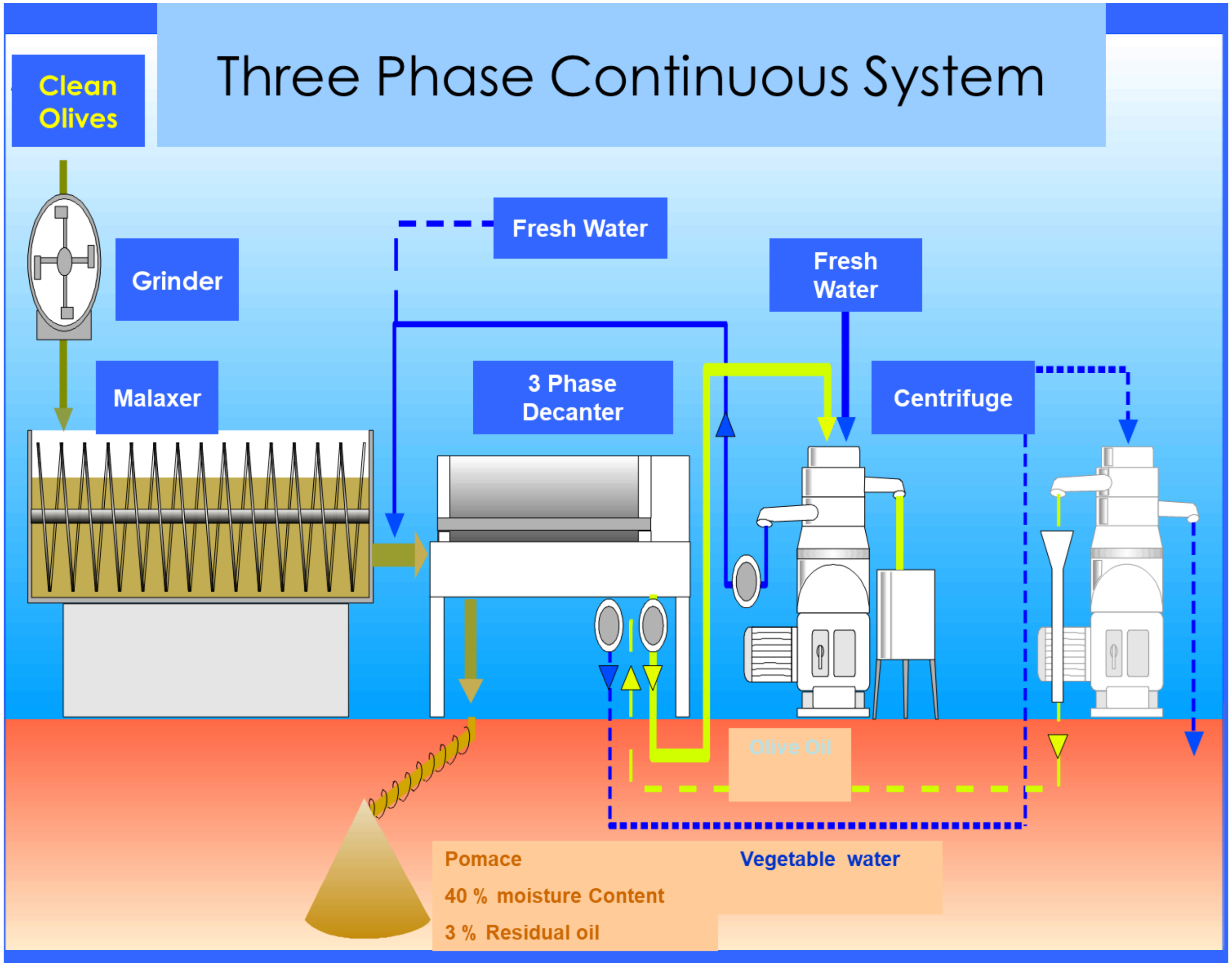
Continuous Three-Phase System



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Continuous Three-Phase System

Advantages:

- Simplifies the mechanical procedures.
- Decreases labour requirements.
- Allows continuous production and hence higher OO production rate.

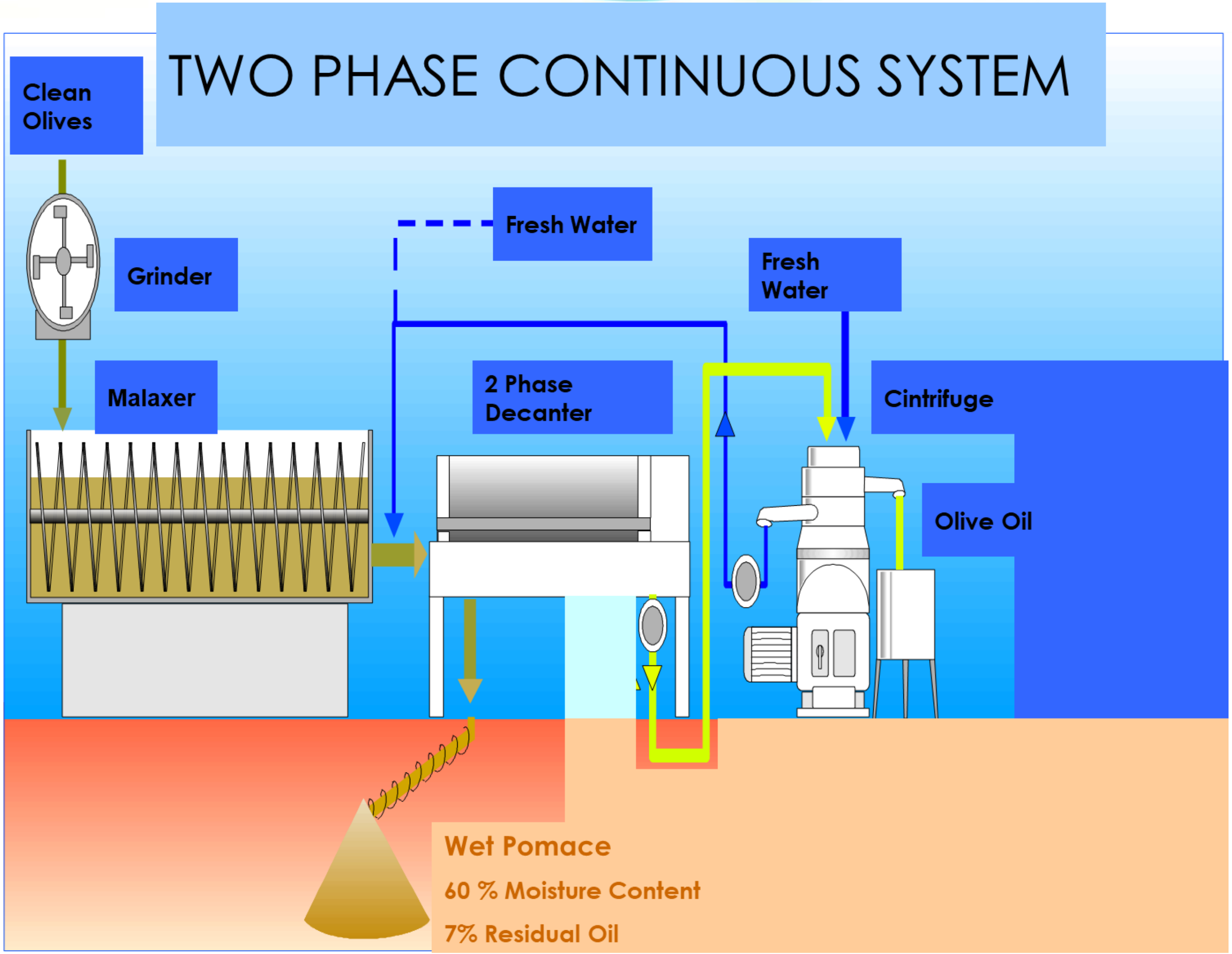
Disadvantages:

- Higher consumption of water (up to 1300 L of water/ton of olives) compared with traditional press.
- Higher energy consumption compared with traditional press.
- Generation of large amount of vegetable water..
- Results in the loss of valuable components from oil (mainly antioxidants).

Continuous Two-Phase System

- Also called the ‘Ecologic’ system.
- Developed to correct the disadvantages of the three-phase system.
- Eliminates the need to add hot water to the decanter and as such no vegetable water is produced.
- Modified decanters are used to produce:
  - Oil.
  - Spent olives (wet pomace).

Continuous Two-Phase System



Continuous Two-Phase System

Advantages (compared with three-phase system):

- Consumes less amount of water.
- Saves on energy.
- Less complex to construct and more reliable.
- Produces higher quality oil (with higher antioxidant stability & better organoleptic characteristics)

Disadvantages:

- Wet pomace has higher moisture, sugar and fine solids contents. Therefore, it is very hard to transport, sort and manage/treat.
- Further cleaning of wet pomace is required by energy dependent vertical centrifugation.
- Less reliable and lower yield than the three-phase system.

Continuous Two-and-a-Half Phase System

- Developed to improve on the two-phase system.
- Includes a new decanter, characterized by VDP (variable dynamic pressure), which means it can be adapted to the characteristics of the paste.

Continuous Two-and-a-Half Phase System

Advantages:

- High working flexibility of decanter.
- Better extraction yield with no compromise of the quality of oil.
- Produces drier pomace, easier to carry and process.

Disadvantages:

- Higher cost of installation.
- Higher maintenance cost.
- Need for specially trained staff.

Stone Removing

- Can be an additional step to other extraction processes.
- Olives are fed to a pulper that separates stones from pulp.
- Pulp is pressurized to extract liquid phase and small pulp proportion.
- Many existing patents.

Stone Removing

Advantages:

- Vegetable water produced has a highly reduced pollution load (less acidic, lower BOD_5, lower amount of organic compounds and suspended solids)=> easier to dispose off.
- Low production and maintenance costs.
- Low energy consumption.
- High yield (no stones to absorb produced oil) of high quality oil production (good phenolic concentration and lower enzymatic degradation of hydrophilic phenols=> better oil oxidative stability).
- Removed stones can be used as an energy source.

Disadvantages:

- Considered a preliminary technique, and de-stoned olives need to be treated in any one of the previously mentioned systems.

Percolation

- Also knows as Sinolea.
- Based on different surface tensions of vegetable water and oil.
- Oil adhere to metal discs, while the other phases stay behind.
- Works by introducing many discs into olive paste, continuously.

Percolation

- **Advantages:**
  - Low labour requirements.
  - Produces oil that has good aroma and flavor.
- **Disadvantages:**
  - Low yield.
  - Resulting paste requires further treatment.
  - High energy consumption.

Emerging/Experimental Techniques

- Electrophoresis.
- Ultrasound.
- Microwave.
- Pulsed Electrical Fields.

Generated Waste

OMW vary widely but have the following common characteristics:

- Dark colouration (dark-brown/black).
- Olives' particular 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 a COD/BOD_5 ratio of 2.5 to 5.
- High concentration of phenols (up to 80 gL^{-1}).
- High organic content.

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Input-Output Analysis of Materials and Energy in Different Extraction Systems

System	INPUT		OUTPUT	
	Item	Quantity	Item	Quantity
Traditional Extraction	Olive	1 Ton	Oil	200 Kg
	Rinsing Water	100-200 Liters	Spent Olives	400-600 Kg
	Energy	40-60 kWh	Vegetable water	400-600 Liters
Three-phase Extraction	Olive	1 Ton	Oil	200 Kg
	Rinsing Water	100-120 Liters	Spent Olives	500-600 Kg
	Additional Water	700-1000 Liters	Vegetable Water	1000-1200 Liters
	Energy	90-117 kWh		
Two-phase Extraction	Olive	1 Ton	Oil	200 Kg
	Rinsing water	100-120 Liters	Spent Olives	800 Kg
	Energy	<90-117 kWh	Vegetable water	100-150 Liters
Two-and a half phase Extraction	Olive	1 Ton	Oil	200 kg
	Rinsing water	100- 200 Liters	Spent Olives	560-600 Kg
	Energy	90-117 kWh	Vegetable water	330-350 Liters

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Characteristics of Wastes from Two-Phase System

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	—

Characteristics of Wastewaters From Three-Phase System

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

Characteristics of Wastewaters From Traditional and Three-Phase Systems

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

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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.

Best Available Techniques

- **As per EU Directive 2010/75/EU:**
  - In general, it means the most effective and advanced stage in the development of activities and their methods of operation.
    - i.e. 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.
  - In the olive oil production sector specifically, it means techniques that are generally considered to have potential for achieving a high level of environmental protection.
    - Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

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Best Available Techniques

- Annex III of the Directive lists a number of considerations to be taken into account.
- A standard structure has been used, enabling comparison of techniques and facilitating objective assessment against the definition of BATs given in the Directive.

Type of information considered	Type of information included
Description	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)

Olive Oil Extraction Technique Selection Factors

- Extraction efficiency (oil yield).
- Desired quality of produced OO .
- Processing time.
- Equipment prices, and staffing practicalities.
- Water and energy consumption.
- Existing infrastructure for the management of by-products.
- Legal framework.

Two-Phase System

Environmental impacts and cross media-effect (compared with three-phase system):

- Continuous centrifugation saves process water by 80% and energy by 20%.
- Greenhouse gas intensity is 9% lower (mainly due to higher emissions in wastewater treatment extraction in three-phase).
- Produces no wastewater but doubles the amount of 'semi-solid' waste (30% by mass), which is difficult to transport, store and handle.
- Transfers the problem of disposing of the olive-mill waste from the mill to seed-oil refineries.
- Endangers solid waste de-oiling facilities operating as recovery units.

Operational data (compared with three-phase system):

- Low or none quantity of water consumed.
- Construction, operation and maintenance is less complex.
- Decanters proved more reliable and less expensive.
- Has a reduced capacity of 20-25%.
- less stable with difficult yield control.

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Two-Phase System

Applicability:

- Has been applied in Spain in 1992.
- All OO producing countries have two-phase decanters.
- Resisted by small mills that enjoy water abundance.
- Resisted by mills who have invested to switch to three-phase and do not want to spend more on another system.
- Can be operated as a three-phase with proper permit.

Economics:

- Savings on energy and water bills by 20 and 80 % respectively.
- Requires 25% less investment cost compared with three-phase.

Driving force for implementation:

- Water and Energy savings
- Prevention of OMWW generation.
- Improves oil quality and preserves antioxidants in oil.

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Case Study:
Switch to two-phase system in Andalucia

- Andalucia has opted to switch to two-phase system by 2013.
- The switch was coupled with a call for composting to tackle wet pomace problem.
- Choice of composting was settled on the aerated static piles system.
- Two-phase compost cost was 3 times less expensive than chemical compost.

Case Study:
Two-phase mill in Meknes, Morocco

- Study conducted in 2017 to assess feasibility and details for an OO mill in rural agricultural area of Oued Jdida in Meknes region in the north.
- Two-phase system (capacity of 450 t/day), treating pomace unit (capacity of 1560 t/day), de-stoning unit (capacity of 1600 t/day) and Stainless steel storing containers (capacity 2000 t) for OO storing.
- Construction of basins to receive wet pomace (volume 9720 m^3), de-seeded wet pomace (volume 14 625 m^3), to prepare pomace for treatment (volume 600 m^3), 4 evaporation ponds (lined reinforced concrete with a geomembrane, total volume 7350 m^3) and borehole or septic tank (volume 75 m^3).

Case Study:
Two-phase mill in Meknes, Morocco

- Total water consumption (100 days of work) is at 10383 m^3 and energy at 921000 KW.
- Expected effluents/season are 8325 t of oil and 2340 t of oil after secondary treatment destined to be stored and bottled. washing waters (5025 m^3), destined for evaporation ponds.
- Wet pomace (135,593 t) destined for drying.
- Leaves (1,575 t) and seeds (23,400 t) valorized as energy source back into the operation.
- Cost of project is ~$40x10^6$euros, 38% of which is for OMW treatment.

Case Study:
Two-phase mill in Meknes, Morocco

- 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 water table by around 15600 t.
- Air and noise pollutions are expected to be minimal.
- On fauna and flora, the impact is expected to be negligible.
- Recommendation to build two-phase mill with destoning capacity and treatment/storage facilities for both water and solid effluents via thermal drying and evaporation ponds.

Three-Phase System

Environmental impacts and cross media-effect (compared with two-phase system):

- Produced wastes are easier to store, handle and dispose of.
- Pomace is lower in fat, dry residue, phenols and diophenols. COD and turbidity is lower as well.
- Consumes more water and energy by 80 and 20% respectively.
  - Can be corrected if proper measurements 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.
- Greenhouse gas intensity is 9% higher.
- OMWW volume is high (can be an asset if by-products are properly re-used).

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Three-Phase System

Operational data (compared with traditional and two-phase system):

- More flexible, stable and has larger capacity.
- Delivers better oil yield.
- Easy to acquire, install, operate and maintain.

Applicability

- First system to replace traditional press mills & now applied in all OO producing country.
- Decreased labour cost dramatically
- Achieved a much higher yield
- Resulted in a more reliable process.
- Easy to acquire, install, operate and maintain.

Three-Phase System

Economics:

- On medium to long term basis, switching from traditional system makes sense as the improvement in yearly yield and quality of OO adjusts for capital cost.
- Abundance of governmental/institutional financial support and assistance for manufacturers to switch to three phase system from the 1970s onwards.

Driving force for implementation:

- Mechanisation:
  - Better productivity (higher yield, better consistency).
  - Improved hygienic standards.
- In areas with water abundance, three-phase is still the system mostly adopted.

Two-and-a-Half Phase System

Environmental impacts and cross media-effect (compared with two and three-phase systems):

- Provides better extraction yield without quality compromise or water addition.
- Drier (than two-phase) but slightly wetter (than three-phase) pomace, which is easy to store, transport and handle.

Operational data:

- Available and reliable.
- Requires special training for the installation, operation and maintenance of the system.
- Timely and financially costly.

Two-and-a-Half Phase System

Applicability:

- Has not been widely adopted because of financial and staffing constrictions.
- Requires governmental and institutional support.

Economics:

- On long term basis, switching to two-and-a-half phase system makes sense as improvement in yearly yield and quality of OO adjusts for the capital cost .
- By-products are easy to handle and treat and can be used as biomass and fertilizers if properly treated.

Driving force for implementation:

- To adjust to the difficulty presented by the two-phase system's wet pomace but not fall back into the shortcoming of the three-phase system.
- Between the two-phase and the three-phase system, providing the advantages of both.

De-stoning Technique

Environmental impacts and cross media-effect:

- Produced vegetable water has a significantly reduced pollution load.
  - less acidic, lower BOD_5 level, and smaller amount of organic compounds and suspended solids (compared with traditional and continuous processes).
  - Free of highly polluting compounds (found in the stones).
  - Stones can be used as an energy source due to their high calorific properties.

Operational data:

- Machines are considerably cheaper than the conventional ones in terms of supply, installation and maintenance.
- Energy requirements and undertaking cost are reduced (smaller nominal engine powers required).

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De-stoning Technique

Applicability:

- It has low operational costs and pollution load.
- Stones can be directly used as a heating source.
- It can be added to any system.

Economics:

- Capital cost is low and machines used are easy to install and maintain.
- Process requires small engine power/not high energy consuming.
- Vegetable waters less polluting => more readily stored, transported and/or treated.
- Stones are a source of income as they can be used to produce heat.
- As olives are de-stoned before malaxing, oil yield and quality are improved.

Driving force for implementation:

- Improving oil yield and quality.
- Reducing energy consumption and pollution load of the generated waste.
- Lower production and undertaking costs.

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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

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Techniques to Manage By-Products

- **Thermal treatment:**
  - Drying.
  - Combustion.
  - Pyrolysis.
  - Evaporation/Distillation (Evaporation ponds/Lagoons).
- **Biological treatment:**
  - Aerobic/anaerobic treatment.
  - Composting.
- **Physico-chemical & advanced oxidation processes.**
- **Direct application in agriculture (as biocides/herbicides).**

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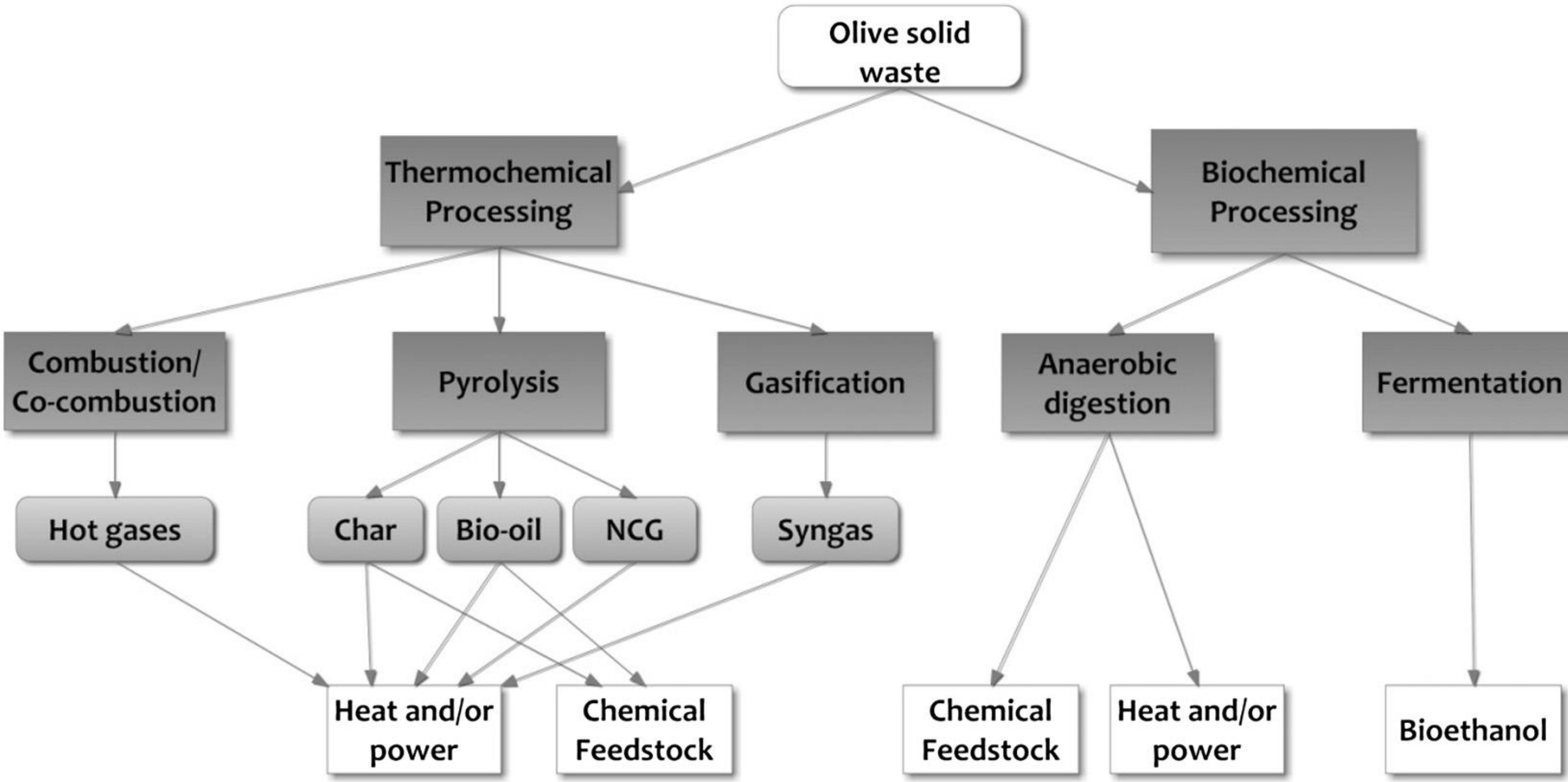
Techniques to Manage Pomace

Waste to Energy Technologies



(Fokaides, 2013)

Drying of Pomace

- Pomace is dried via a heat source (contact, convection or radiation)
  - Water within pomace evaporates and is conveyed by hot gas flow & solid residue is de-oiled with organic solvent and either incinerated for energy production or re-used in agriculture.
- Two-phase pomace is treated in two-rotary driers.
  - The first is fed with mixture of fresh and dried pomace (moisture content around 55%)=> it is dried to 25-30%.
  - Second drier dries it to below 8%.

Drying of Pomace

Environmental impacts and cross media-effect:

- Drying results in easier storage and transport conditions.
- Treatment with organic solvent allows the residue to be used for energy production, reused as a fertilizer or to be safely disposed of in landfills.
- The main disadvantage is the high energy demand needed to achieve a moisture content of 5-8%.
- Drying produces air emissions that must be treated appropriately.

Operational data:

- Heating requires the purchase, operation and maintenance of heating drums => more cost (from staffing and physical facilities' perspectives).
- Very high energy consumption and pollutant emissions => adds up to the air pollution management bill.

Drying of Pomace

Applicability:

- Drying with its resulting by-products means that waste has been valorised and its negative environmental impacts majorly reduced.
- However, especially in the case of two-phase wet pomace, from an operational and energy-saving point of view, the high energy cost remains a major obstacle.

Economics:

- High investment and operating costs and personnel are required for drying plants.

Driving force for implementation:

- The environmental benefits resulting from managing the highly polluting pomace remain the main attraction for drying.
- In addition, the resulting valorisation of the by-products in energy production and/or agricultural use as fertiliser/herbicides makes drying an attractive solution especially if energy is being recycled in the system.

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Composting of Pomace

Environmental impacts and cross media-effect:

- Avoids landfilling of harmful wastes.
- Resulting by-products can be used as soil enricher/fertilizer.
- Generated heat can be recycled=> reduce air pollution load cost.
- Minimal cost and labour if mechanical turning is involved.

Operational data:

- Requires minimum staff, machinery and space.
- Has been widely used.

Applicability:

- Its resulting by-products mean that waste has been valorised and its negative environmental impacts majorly reduced.
- Financial and technical easiness makes it widely applicable.

Composting of Pomace

Economics:

- Low investment and operating costs and personnel.
- Valorization of generated heat and resulting fertilizers.

Driving force for implementation:

- The environmental benefits resulting from managing the highly polluting pomace.
- In addition, the resulting valorisation of the by-products in energy production and/or agricultural use as fertiliser/soil enricher.

Case Study: Pomace Composting in Tunisia

- **In central urban region of Sfax, 400 mills produce 150x10^3 tons/year of pomace.**
- **Pomace composted by:**
  - Adding locally produced cow manure at 2/1 ratio reaching a C/N ration of 35.
  - Mechanical turning for aeration every 5-10 days, keeping humidity at 55%.
  - Maturation of compost was achieved in 110 days.
- **Compost spread at 100 m^3/ha leading to:**
  - Increase in soil fertility, organic and mineral content and soil electrical conductivity.
  - pH not affected.

Open Composting

Mechanical Turning of Compost

Aeration of Compost

Anaerobic Digestion of Pomace

Environmental impacts and cross media-effect:

- Turns harmful wastes into usable by-products, namely biomass for heat.
- Recycling of heat translates into lower air pollution load.

Operational data:

- Easy and safe.
- Low cost.
- Requires pre-treatment.

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Anaerobic Digestion of Pomace

Applicability:

- Easy technically.
- Low cost.
- Heat production.

Economics:

- Valorization of waste.
- Lowering the pollution load cost.

Driving force for implementation:

- Technical and financial readiness.
- Valorization of waste.

Combustion

Combustion is burning of fuel in excess air resulting in heat production. From the biomass, combustible vapours become volatile and then burn as flames. This occurs in three fractions:

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

- **Widely common to burn exhausted olive cake to produce heat, mostly to cover drying energy needs.**
- **Co-combustion is also widely used. It is the addition of supplementary fuel to the main one and the simultaneous firing of both in the same chamber. It presents an advantage in the disposal of wastes and a reduction in fuel cost.**

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Combustion

Environmental impacts and cross-media effects:

- Avoiding harmful wastes being landfilled without treatment.
- Produced energy is recycled into the system, avoiding further cost and additional air pollution load.
- Power production can be done by resorting to secondary conversion technologies.
- It remains a high energy demanding process and resulting air pollution has to be addressed.
- Biomass substitution ratio is very limiting (because of its combustion properties) => complications in the system.

Operational data:

- Human, technical and physical resources are widely available and easy to attain => combustion is a widely used option.

Combustion

Applicability:

- One of the mostly applied techniques in the management of OMW.
- Burning of biomass for heat purposes is a very appealing and easy to implement option.
- It provides a cutting in fuel cost by recycling of overall energy input and output within the system.

Economics:

- Because of its operational applicability, its reduction of energy bill and valorisation of biomass product, combustion presents an economically viable option.

Driving force for implementation:

- Easiness, both from a financial and staffing points of view.
- Production of a valorised by-product that can be recycled to reduce the energy consumption.

Pyrolysis

- **Is a thermochemical method to convert a biomass to liquid, solid and gaseous fractions by heating without an air element.**
- **There is slow, fast and flash pyrolysis based on temperature and rate of heating.**
  - Slow pyrolysis =>low temperature and heating rates => vapour residence time is high, varying between 5 minutes to half an hour, leading to char production.
  - Flash and fast pyrolysis=> heating rates and temperature are relatively high => to higher production of gases. In fast pyrolysis, a short vapour residence time is applied. In flash pyrolysis, a very short gas residence is applied (less then 1 second).

Pyrolysis

Environmental impacts and cross-media effects:

- Benefit of avoiding harmful wastes being landfilled.
- Produced oil (especially in the fast method) is used as fuel oil to produce electricity or as refineries' feedstock.
- However, it requires high energy consumption to provide for the high temperature and heating, contributing to air pollution load as well. However, this can be overcome by recycling energy within the system and properly treating exhaust.

Operational data:

- It is expensive and sophisticated, requiring high capital investment, close monitoring and regular maintenance by skilled labour.

Pyrolysis

Applicability:

- In the absence of proper financial resources, technical knowledge, and continuous staff training => pyrolysis is not easy to adopt especially in small and medium sized mills.

Economics:

- Requires high cost and proper training and financial support. As such, it has remained an option for only well resourced and/or governmentally supported operators.

Driving force for implementation:

- Environmental benefit of recycling harmful waste into fuel constitutes the main driving force.
- 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.

Techniques to Manage Vegetable Water

Evaporation/Distillation

- Vegetable water is separated into a residue containing non-volatile organics and mineral salts, and a condensate that consists of water and volatile substances.
- Evaporation differs from distillation in that when the volatile stream consists of more than one component, no attempt is made to separate these components.
- Evaporation reduces waste volume by at least 70-75%, bringing down its polluting load to 90% in terms of COD.
- Evaporation makes storage and handling of residue feasible and easy.
- With one additional treatment step, such as biological treatment, residues, much smaller in size and volume can be safely disposed of in mainstream waste routes.

Evaporation: Evaporation Ponds/Lagoons

- Vegetable water is disposed of in artificial evaporation ponds or storage lakes. Solar energy is used to speed-up the process.
- It is partially degraded by a natural biological route, over long periods of time. 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.
- Lagooning has been used for pollution control, vegetable water disposal as fertilizer after solar drying, and for storage in order to obtain load equalization during the whole year before treatment by other processes.

Evaporation Ponds/Lagoons

Environmental impacts and cross-media effects:

- Risk of vegetable water leaking through the soil into the groundwater. Using proper liners and suitable maintenance is vital.
- Requires the availability of large collecting basins at a distance from residential areas because of the unpleasant smell of vegetable water and the strong acetic acid smell (due to anaerobic fermentation) & the presence of insects.
- Lagoons have to be located 1 or 2 km away from olive mills, so proper piping is needed to transport the vegetable water without 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 rendering them useless for active agriculture.
- The end product is useless as fertilizer, or for irrigation.

Evaporation Ponds/Lagoons

Operational data:

- Material and labour force (available and easy to install) have to be factored in when deciding on the operationality of the process.
- Factors affecting the process include:
  - Volume of vegetable water produced by each of olive-mills to be serviced.
  - Climate of the region.
  - Hydrology of the ground.
  - Proximity to natural waters.
  - Distance from residential areas.

Applicability:

- It is very widely used in Mediterranean countries.
- The most developed one are the 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.

Evaporation Ponds/Lagoons

Economics:

- 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 €) is difficult because it depends on the type of the soil and the distance from the disposal site.
- In addition to the cost of digging, the cost of sealing should be taken into consideration (a pond of 1000 m^2 is estimated to cost between 16,000 and 20,000 €).

Driving force for implementation:

In areas with relatively low land cost and availability of large surfaces, lagooning presents the advantages of low investment and maintenance cost for a treatment solution for vegetable water. This is the case only when it is done properly, with proper piping and lining.

Case Study : Vegetable Water Evaporation in Tunisia

- **In central urban region of Sfax, 400 mills produce 250x10^3 m^3 of OMW/year and 150 10^3 tons/year of pomace.**
- **They are being processed in evaporation ponds 350 km away.**
- **Soil is semi-arid receiving 200 mm rainfall/year.**
- **OMW used as liquid fertilizer at 50 m^3/ha.**
  - Soil pH not effected
  - Organic matters increased by 0.45%
  - K&P but not N contents increased.
  - Yield of olive tree improved by 83% within 2 years of application.
  - Total cost of 8.1 Tunisian Dinar of OMW spreading (8,200 TND for evaporation).

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Biological Treatment

- Vegetable water is considered a great source of biologically active phenols (bio-phenols) because of its high content of phenolic compounds, widely recognized as antioxidants that can be used in many industries (food and pharmaceutical companies).
- Microbiological processes have interesting potential because they have less impact on the environment and, in most cases, can be profitable because they lead to value-added products such as enzymes, biofuels and biopolymers.

Biological Treatment

- Aerobic, anaerobic and combined treatments.
- Aerobic biological treatment have been proposed using several microorganisms such as Pleurotus ostreatus, Bacillus pumilus, Chrysosporium hanerochaete, Aspergillus niger, Aspergillus terreus, Geotrichum candidum, Azotobacter Vinelandii, Candida Oleophila etc.
- Anaerobic technology treat wastewater and produces biogas that can be used as a primary energy resource at the local level.
  - For an efficient process, wastewater should have a balanced C/N/P ratio and a pH between 6.5 and 7.5. Although vegetable water has an unbalanced ratio, there are studies that mixing it with nutrient-rich streams, co-substrates, greatly improves the performance of the process.

Biological Treatment

- **Pre or post treatments:**
  - Using membrane technologies: ultrafiltration, nano-filtration and reverse osmosis.
  - The use of ultrasound for the deconstruction.
  - Alkaline hydrolysis and addition of calcium carbonate.
    - An important aspect to consider when choosing a pre-treatment is the net energy balance; Increase in biogas production (Biochemical methane potential rating (PMB)) should clearly offset energy intake (energy sustainability index (IDE)).
    - The co-substrates mostly used/studied for co-digestion of vegetable water is manure, because it contributes to nutrient balance, has a high pH and has a high buffer capacity.

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Composting of Vegetable Water

- Is one of the main technologies for recycling OMW and transforming it into a fertilizer.
- Waste could be absorbed in a solid substrate (lignocellulosic wastes or manures) before composting.
- Includes three phases: initial activation, a thermophilic (heat rise) and a mesophilic (heat drop) phase.
- OMW can be composted either on its own or mixed with other by-products (such as poultry and sheep manures, wool waste, wheat straw, wood-chips and rice-by-products) that basically act as bulking agents.

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Composting of Wastewater

Environmental impacts and cross-media effects :

- Avoid wastes being landfilled without treatment.
- Produced heat can be recycled into the system, avoiding further cost and additional air pollution load.
- If mechanical turning is used instead of forced aeration, minimal cost (in energy or capital) is necessary.

Operational data:

- Composting requires minimal and affordable equipment and staff. It is a simple process to execute and appeals as such to small, medium and big mills.

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Composting of Wastewater

Applicability:

- Compost produced has been used with positive outcomes as agricultural fertilizer or soil enhancer.
- Ease of the process and the low budget involved make composting a very appealing and easy to achieve treatment plan.

Economics:

- Because of its operational applicability as well as the valorisation of the biomass product, composting of OMW presents an economically viable and a widely used technique.

Driving force for implementation:

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

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Physico-chemical & Advanced Oxidation Processes

- Flocculation of coagulation is a common pre-treatment technique. It is often coupled with filtration steps.
- Advanced oxidation processes: electrochemical, ozonation (O_3), catalytic oxidation, and UV.
- Oxidation techniques are often followed by biological treatments.
- Most of these techniques have been used as pre or post-treatments.
- Most of these techniques remain laboratory-based.

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Direct Application of Vegetable Water in Agriculture

- Vegetable water can be used to suppress the growth of main weed, bacterial and fungal phytopathogens, without negative effects on crop growth.
- It proved its biocide effect on some pests, molluscs and arthropods.
- C*ontrolled* spreading of vegetable water (in the order of 100 m^3/ha/year) on agricultural land have a positive effect on olive plantations, grape wine, corn or sunflowers.
- When low wastewater volumes are used, soil acts as a bio-filter and process becomes beneficial to the soil.

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Case Study:
Irrigation with Water Vegetable in Syria

- Common practice in Syria.
- Case studies in Daraa area.
- Vegetable water produced from traditional and three-phase system mills.
- Spread in 50m^3/ha (traditional mills) & 80 m^3/ha (three-phase mills).
- Added to trees 50-70 cm away from trunk.
- Added 30-60 days before planting and 30 days before implants.
- Was at least 500 m away from urban clusters and 1000 m away from drinking water source.
- Was not used in oils with ground water level at 10 m depth, over-flooded or richly watered soil, in riverbanks and stream sides or in roughly inclined terrains.
- Agricultural landscape improved with savings resulting from using vegetable waters and in Environmental Degradation Cost avoided by using the by-product.

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Irrigation with Vegetable Water Using Closed Truck

Theoretical Case Study: OMW Management in Lebanon

ELARD 2008 study: several scenarios with CBA.

- Option 1: Switch all existing traditional press mills (88% of mills) to two-phase mills.
- Option 2: lime pre-treatment of OMW.
- Option 3: use OMW to for irrigation.

Theoretical Case Study: OMW Management in Lebanon

Option 3 (OMW for irrigation):

- To reuse all the OMW generated in Lebanon for irrigation, there is need for only 4-10% of olive cultivated land.
- Decrease in water irrigation cost and OMW treatment cost
- Decrease in cost of environmental degradation
- Increase in annual savings in fertilizers usage between $400x10^3$ to $900x10^3$ USD.
- Option very desirable.

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Theoretical Case Study: OMW Management in Lebanon

Option 2 (lime pre-treatment):

- Will cost between 74-350 USD/mill/season => 103-1.5x103 USD/mill (including dosing system, aerotors and mixers).
- Produces a less polluting water for irrigation use and a sludge that can be used for domestic heating.
- Option feasible and beneficial.

Theoretical Case Study: OMW Management in Lebanon

Option 1 (switch to two-phase):

- Expenses were calculated between 92 $x10^6$ -155 $x10^6$ USD, while benefits with Cost of Environmental Degradation to reach around USD 74 x 10^6 and without Cost of Environmental Degradation to be 151 x $10^{6.}$
- Cost of storing, transporting and labour for irrigation with resulting OMW around 5 USD/m^3 which translates to 1.4 x 10^6 for high production season and 610 x 10^3 for low production season.
- Option had to be dropped.

Theoretical Case Study: OMW Management in Lebanon

- CARTIF foundation argued against proposed treatments as partial solutions and suggested the implementation of an integral treatment plant with treatment and post treatment facilities.
- Treatment phase includes a mechanical drying step, followed by a quick separation of solid waste phase and finishing with a thermal concentration process.
- The post-treatment plant includes a composting plant and manufacturing for liquid organic fertilizers plant.
- These plants will produce pits with high calorific value of $4x10^3$ Kcal/Kg => use as a biomass.
- Such plant will improve yield and quality of oil and produce solid waste that is suitable for composting.
- Concentrated liquid waste produced will be suitable for organic liquid fertilizer and inorganic liquid fertilizer.
- Water used in the system can be used for irrigation with no water lost as vapor.

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Extraction technique remains the MAIN parameter determining the concentration and physico-chemical/ biological nature of produced wastes => focus in deciding on BAT to manage OMW will be on the used extraction technique and whether or not it can be modified or changed.

Analysis will cover most used/applicable techniques

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

BAT conclusions can be applied to all mills, and will cover:

Water efficiency
Energy efficiency
Liquid waste
Solid waste
Noise pollution

BAT 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

BAT 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

BAT to Reduce Noise

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

BAT 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

BAT for 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

BAT for 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

BAT Tabulation

	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

Scale of Evaluation/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.	Easy 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.

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Parameters Considered for Environmental Impacts

	Environmental Impacts
Significance	How it changes existing environmental conditions and whether such change can be mitigated or not.
Nature	Whether it affects negatively or positively, directly or indirectly.
Magnitude	Range of effects on physical, biological and human environments and whether it is affecting areas that are degraded or of high conservation value.
Extent	Local or global.
Duration	During construction or operation.
Timing	Short, medium or long term.
Reversibility	Reversible or not.
Likelihood of occurrence	Very likely, likely or unlikely.

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Summary of Applicable Techniques

TABLE 1: 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.

Summary of Applicable Techniques

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

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

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Techniques to Treat Various Effluents of 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

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Outline of MENA OO Milling Sector

- Prevalence of traditional mills, followed by three-phase then two-phase system mills.
- Sporadic scattering of small to medium sized mills, mostly in rural areas.
- Long dry seasons.
- Wide variation of geological and topographical formation (with prevalence of limestone and equally absorbent and fertile soils).
- Abundance of water supply especially during the rainy season.
- Availability of land, fairly cheap labour force as well as relatively lenient environmental laws and/or weakness in their implementation.

BAT Recommendations

Based on the above outlined milling profile and the conducted analysis, the recommendations are to:

- Switch existing mills into either two-phase or two-and-a-half phase system mills along with the addition of a de-stoning step. This will ensure *least* environmental damage and is economically *viable*.
- Resulting effluents should be treated via composting and lagooning as well as direct land application as soil enrichers or fertilizers.
- Recycling of heat and water needs to be an integral part of all mills.
- These techniques need to be individually assessed for each area to decide on the *best dose, timing and manner* of composting, lagooning and land application as *topographical and geological* profiles as well as *the nature* of the olive fruit and the resulting effluents dictate variations in the treatment.

BAT Recommendations

Besides technical solutions, there should be:

- A legal framework 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 expanded to other countries like Libya and Palestine. Moreover, guidelines for the establishment and operation of olive mills should also be put in place in some countries like Libya, Algeria, etc...
- Proper enforcement of legislation.
- Economic incentives or disincentives that would encourage the use of BATs and BEPs and penalize environmental polluters. An example of 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 solution and treatment methods to create economies of scale and mutual benefits (Hamdan, 2019).
- Training of olive mill owners and other stakeholders on the proper management of olive mill waste.

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For further information

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Thank you for your attention

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