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HYDROUSA

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Water in the context of circular economy

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Development of High Added Value Products

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Brief Description	This document provides detailed information on tasks carried out within the project regarding the production of high added value products at the demo sites in collaboration with our local partners.
Keywords	Aromatics, essential oils, distillation, hydrosols, cosmetics.

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EXECUTIVE SUMMARY

Essential oils and hydrosols are considered the most valued products aromatic plants can offer. They can be promoted pure, in wholesale or retail sale, but even better they can be further processed to produce cosmetics and herbal formulations, which in turn have the potential to find their way into the local market more easily. This deliverable describes the process implemented for the development of high added-value essential oils and hydrosols produced from herbs at the agricultural sites of Mykonos, Tinos and Lesvos and their further on-site valorisation in the formulation of creams, ointments and lotions. The document reviews the actions taken, the challenges faced, and the results recorded.

The HYDROs involved in the production of high added value products are HYDRO2 on Lesvos Island, HYDROs 3 & 4 on Mykonos Island and HYDRO6 on Tinos Island. On Lesvos and Tinos, a limited part of the crops planted is dedicated to aromatic plants, while on Mykonos HYDRO3 and HYDRO4 are planted with aromatic plants only. These four demo sites are irrigated by the non-conventional water sources developed and demonstrated in the HYDROUSA project.

The workflow faced significant challenges due to the pandemic restrictions, resulting in delays in various critical activities, including planting crops, acquiring and constructing distillers, and establishing contact with relevant authorities. Additional challenges were encountered stemming from adverse weather conditions such as freezing temperatures, snowfall, and droughts, as well as several plant diseases that affected a portion of our crops. Consequently, we experienced losses in our aromatic plant inventory, prompting us to embark on a replanting effort in both 2021 and 2022 to mitigate these setbacks.

After harvesting, the aromatic plants were dried and prepared for distillation. Distillation units were purchased and installed at two demo sites, in Mykonos and Tinos Islands. ALCNGR (affiliated party of ALCN) directed and assisted the demo site leaders in this task, guided them in performing the distillation process and instructed them in the formulation of creams, lotions and ointments. The resulting essential oil (E.O.) and hydrosols produced, are promoted and distributed locally pure, or in formulations produced by the producers themselves. In this case local producers are empowered to add value to their initial product (dried aromatic plants), upgrade it and promote it in the local market.

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ABBREVIATIONS

E.O.	**Essential Oils**
DEL	**Ntelaros OE**
NTUA	**National Technical University Athens**
ELT	**Ecolodge Tinos**
ALCN	**Alchemia-Nova GMBH**
ALCNGR	**Alchemia-Nova Greece**
NBS	**Nature-Based Solutions**
WICC	**Water Innovation & Circularity Conference**

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1. INTRODUCTION

This document provides an overview of the actions and progress made in the execution of Task 4.4, which focuses on the development of high-value-added products. Given the project's involvement in agricultural activities, it entails the cultivation of various crops, including both edible and aromatic plants, across the three demonstration sites of HYDRO2, HYDRO3 and HYDRO6. Specifically, our project partner DEL oversaw activities on Mykonos Island, NTUA managed operations on Lesvos Island, and ELT took charge of activities on Tinos Island.

The purpose of this task is to demonstrate pathways after harvesting the plants for further development and exploitation potential. For these two different kinds of crops (edible and aromatic), different pathways are provided. The edible plants are either given to local residents, markets, or restaurants for consumption. For the latter ones, which is the focus of this deliverable, additional pathways have been planned. Aromatic plants offer versatile applications, whether used fresh or in their dried form. When dried, they can be conveniently packaged and made available at local markets or retail stores, or distributed for consumption within the community. In their dried state, these plants serve multiple purposes, including imparting delightful aromas, as flavourful spices, and as herbal infusions known for their therapeutic benefits. However, in order to receive a product with even higher added value, distillation emerges as a reliable and rewarding route. Through distillation, we can achieve the production of two valuable by-products: essential oils and hydrosols, further elevating the potential of these plants and their applications.

Distillation is a process widely used in organic chemistry and beverage industries to obtain a variety of products. It is termed as: "*The process of separating the components or substances from a liquid mixture by using selective boiling and condensation, usually inside an apparatus known as a still.*" (Harwood and Moody 1989) Aromatic plant distillation results in two valuable products as stated above, essential oils, or volatile oils and hydrosols, or flower/aromatic waters. Essential oils, or volatile oils are defined differently by every professional branch working with them (Katsiotis and Chatzopoulou, 2010). Nevertheless, in an attempt to find a term as a reference in this document it is quoted: *"An essential oil, or volatile oil – the two expressions are considered synonymous – is a volatile mixture of organic compounds, which are received by natural means from a plant material (mainly) with odour (aroma). More specifically, an essential oil is derived from a botanical source, (usually aromatic and/or pharmaceutical plants) with which it agrees in both name and odour.*" (Katsiotis and Chatzopoulou, 2010).

The hydrosol, or hydrolat is a valuable by-product of aromatic plant distillation, made of the distilled water resulting from the process, a small percentage of essential oil, less than 1% and most if not all the water-soluble constituents of the plant. It is termed as: "*colloidal suspensions of essential oils as well as water-soluble components obtained by distillation.*" (Price L. and Price S., 2004). Hydrosols are produced in litres at each distillation, as it is the water used for the distillation after its condensation.

While essential oils yield amounts to only a small percentage of the plant biomass used for distillation, it varies greatly from crop to crop and can be affected by many factors, such as soil, water availability and the climate.

Both essential oils and hydrosols have various uses especially in the perfume and cosmetics industry, but they are also highly valued and used by other sectors, such as in aromatherapy, as well as the botanical, agricultural and pharmaceutical ones for their therapeutic applications and valuable chemical components. Essential oils are mainly used in small quantities and diluted in formulations, as they are "strong", meaning they have a very strong aroma concentrated composition and in most cases can cause irritation when used directly on the skin. Therefore, they cannot be applied directly to the body (with few

exceptions). Hydrosols are often replacing water in cosmetic formulations, are much "lighter" and have various direct uses on the skin or in food production. Cosmetic companies specialising in products for sensitive skin, prone to allergies and adverse reactions often prefer to use hydrosols instead of essential oils. Both appear to be stable over time and have a long shelf life (Garneau *et al.* 2014; Katsiotis and Chatzopoulou, 2010). For the HYDROUSA demo sites a workshop organised by ALCNGR was conducted, demonstrating possibilities for further exploitation of the essential oils and hydrosols produced during the project.

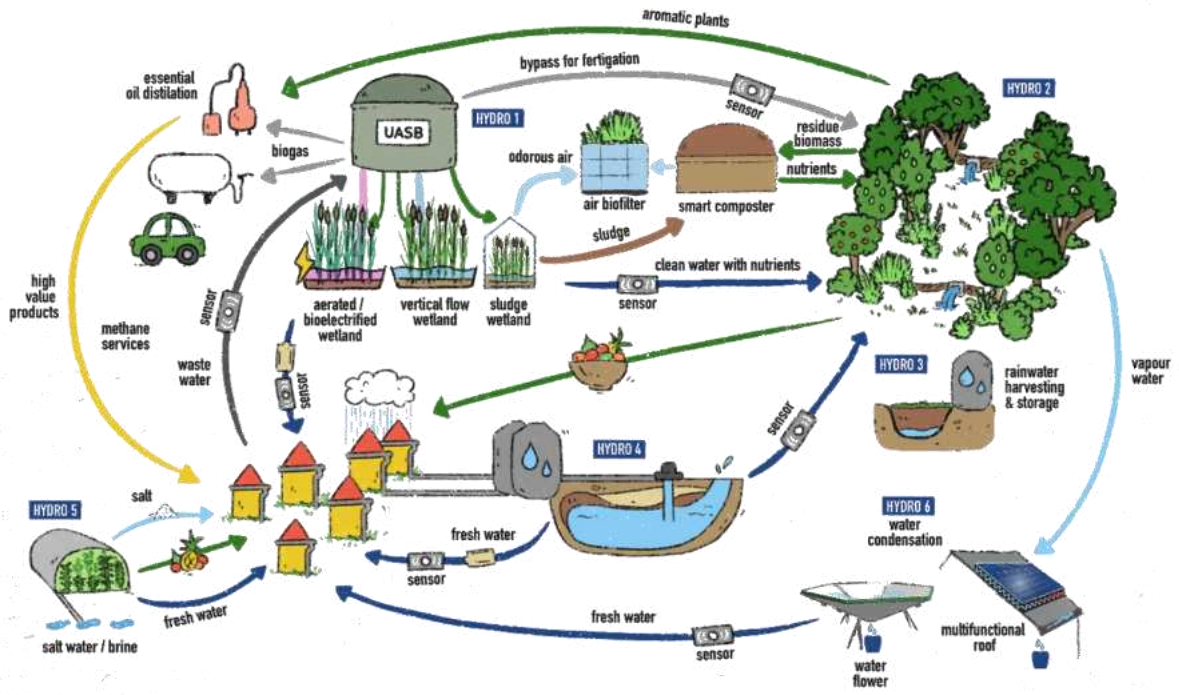

Figure 1.1 Circular material flows demonstrated in HYDROUSA

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2. METHODOLOGY

2.1. Identification of needs

Within Task 4.4 a meeting was organised by ALCNGR in January 2021. The meeting took place online, with all participating parties present and the coordinator. The purpose of that meeting was to identify the needs of the demo sites in relation to the distillation process and outcome.

HYDRO2 is an agroforestry system with a wide diversity of trees, shrubs, aromatic plants and annual crops and is located on Lesvos Island. The demonstration site is irrigated with nutrient-rich reclaimed water that is produced in HYDRO1 demo site which treats the municipal wastewater from Antissa village. The site has an area of 1 ha and is divided into 2 fields. The main field of the site has an area of about 0.8 ha and includes more than 60 different plant species while the second field includes a seasonal plantation of maize/barley accompanied with some aromatic plants and trees (lavender, oregano, rosemary, sage, savoury, melissa, mint, annice, pelargonium, basil, thyme).

HYDRO3 is located in Ano Meria, Mykonos Island. It is an innovative, nature-inspired rainwater harvesting system consisting of a shallow, sub-surface rainwater collector, having a total water storage capacity of 60 m^3. The harvested water is used to irrigate 0.4 ha of oregano cultivation using a drip irrigation system. HYDRO4 is also located in the small village of Ano Meria, on Mykonos Island and the agricultural area cultivated is about 0.2 ha. The HYDRO4 system is based on collection of rainwater and surface runoff which is stored in tanks and into the aquifer. The water is used to irrigate the above stated field which is planted with lavender.

HYDRO6 is a micro-scale implementation site for a whole set of interacting nature-based solutions proposed, developed, implemented and tested within the HYDROUSA project. The demo site is located at Potamia, Akeratos, on Tinos Island on the premises of the Tinos Ecolodge. The premises cover an area of 6000 m^2 and have a hosting capacity of 13 customers. The basic agricultural activities of ELT are a market garden, which produces a high variety of fresh vegetables, a mixed herbs cultivation, which aims at fresh herbs and dried for essential oil production, respectively creams and dedicated workshops. The total allocated area for agriculture is 2.230 m^2 and is subdivided by intensively managed crops with 544 m^2, medium with 550 m^2 and extensively with 680 m^2. More detailed information about the HYDROs and the crops are given in Deliverable 4.5 (Report on yields, health of crops and derived products).

The next step was the decision on the kind of distillers that would cover the needs of each demo site (HYDRO3&4 and HYDRO6). The distillers would be bought and managed by the two entities DEL and ELT on Mykonos and Tinos Island respectively. During the meeting organised for the selection of distillers, it became apparent that the two demo sites, were interested into two different use cases, which in turn determined the size and type of distiller they needed on site. On Mykonos Island, which is highly touristic, DEL wished to distil the whole of the production of aromatic plants harvested from HYDRO3 and HYDRO4, increasing the value of the harvested Oregano and Lavender. The distilled oils and hydrosols find a market on the island, ready to absorb them. Hotels, restaurants, spas and other tourist facilities are looking for sustainably, locally produced products which can be used and promoted in their facilities. Thus, this led to the conclusion that a larger, professional distiller was required for DEL, one that could provide the desired distillation volume, ease in production and a good quality result. On Tinos Island, ELT is itself a tourist facility with a small production of aromatic plants. The distillation process in this case would be for demonstration and educational purposes in workshops performed at ELT's facilities. For this purpose, a small, home/non-professional distiller was thought to be sufficient to cover their needs.

On Lesvos, some quantities of aromatic plants were distilled at a local existing distillation facility and used locally and some quantities were sent to Mykonos for distillation. On this island, it was decided that aromatic plants produced would also follow different valorisation pathways, would be given to the local community, or restaurants and local shops, dried or fresh for further use and exploitation.

2.2. Research on plants planted, EO distillers, best options, best yields

Initial research on the plants was conducted. The plant species to be distilled are also a determining factor for the choice of the distiller. On all three demo sites lavender and oregano are being planted. In HYDRO2 melissa and sage were also planted and distilled.

2.2.1. Oregano

Oregano is endemic in Greece and the broader Mediterranean area. Approximately 75% of the species are present in the East Mediterranean area, while only a small percentage is met on the West Mediterranean. The genus *origanum* includes a great number of different taxa - 49 species and subspecies. Greek oregano, *origanum vulgare spp. hirtum*, is considered to be the best in the world (Fleisher and Sneer 1982). It is found growing wild on bright spots, at middle and low altitudes. It thrives on semi-mountainous areas, relative cool and on fields which have a calcareous, dry soil regardless of the soil quality. Its cultivation requires long periods of light, up to 12 hours. However, the oil producing glands in the plant are not so much affected by the period of light, as much as from the growth stage of the plant; they multiply as the plant develops. Oregano plants can remain on the field for up to eight (8) years, or more. Although the plants withstand drought, watering them is essential for the increase in plant mass and necessary after planting and harvest.

Harvest happens at full blooming of the plant when the plant mass is destined for distillation. The harvested plants are left to dry for a short period of time, 1-2 days and then they are distilled. This drying process is leading to a decrease in the water content and increase in the essential oil content in the plant. The stems of the plant may be separated from the leaves and flowers, but this is not necessary. Essential oil produced only from the flowers is considered to be of higher quality, however the stems and twigs contain also a small percentage of essential oil.

Table 2.1. Oregano E.O. yields

Plant Part	Essential Oil Yield
Fresh plant parts	0.07 – 0.3%
Dry leaves and flowers	0.5 – 2.3%

The quantity and quality of the plant biomass produced is improving from one year to the next and the same is valid for the production and quality of essential oils. The main constituents of oregano essential oil are the monoterpene phenolic substances *carvacrol* and *thymo*l. Others are *π-cymene* and *γ-terpene*, substances consider to be precursors of thymol and carvacrol equivalently as well as the sesquiterpenes caryophyllene, β-bisabolene, flavones, flavonoglycosides, catechins (naringin, luteolin, apigenin) and phenolic acids (rosmarinic, caffeic, hydroxybenzoic and others) (Katsiotis and Chatzopoulou, 2010).

The most common use of oregano is in the food industry. A spice initially loved and used in the Mediterranean; it is now broadly used all over the world. However, except of its traditional culinary uses, research has shown that it possesses a broad spectrum of biological properties, such as antimicrobial and antifungal properties against a variety of pathogens which affect animals and plants (*Aligiannis et al.* 2001; Deans and Svoboda 1990). These properties seem to be in a great extend depending on and influenced by the presence of carvacrol in the plant, and appear to be enhanced when the percentage of carvacrol in the plant increases (Colin *et al.* 1989). Oregano essential oil has also proven to have antioxidant activities

(Castilho *et al.* 2012; Han *et al.* 2017). The above properties of oregano oil, deem it suitable for a variety of uses, both in the food and agricultural industries, and in the human health sector as well.

2.2.2. Lavender

Lavender is nowadays cultivated all over the world, from Australia, to Russia and Spain. However, it is a plant endemic to the South of Europe and the Mediterranean countries. Lavender is the common name for the genus *Lavandula* of the *Liliaceae* family of 39 species of plants. Of those only three are commercially exploited and cultivated. They are perennial shrubs bearing distinctive flowers with a variety of colours ranging from deep purple to intense blue, while some pink, greenish and white varieties are also met. The genus *Lavandula* was initially split into two three parts, a separation that was revisited and reviewed leading to a more recent spilt into six categories: *Lavandula, Stechas, Pterostoechas, Dentata, Haetostachys* and *Subnuda*. Of all the above, the species belonging to the Lavandula category, appear to be the most durable providing us with essential oils bearing the most desired properties. The plants belonging to the other groups produce also essential oils, but with a less commercial value, due to their undesirable scent. The *Lavandula* category includes *L. angustifolia, L. latifolia, L. X. intermedia*, or else *L. hybrida*, also called *lavandin*.

In the HYDROs *L. angustifolia* was chosen to be planted. It is also known as “true lavender”, it is more robust and withstands even very low temperatures. The plant needs long sunny periods for optimal growth and yield. However, very hot summers and warm winters are not optimal. A warm and hot/dry climate may delay growth and significantly reduce the quality, while a cold winter period is necessary for full bloom to occur. It is interesting to compare the results from the analysis of the essential oils produced from plant biomass harvested from the different HYDROs, as well as to compare the yield of E.O. production. The three demo sites are situated in different altitudes and have distinct differences in their local climate.

L. angustifolia is stable in periods of drought, however irrigation is important especially in the period after planting, harvesting and in areas which are warm, dry and windy, such as Mykonos and Tinos Islands. The lack of water could reduce the number of flowers per flowerhead and thus lead to a decrease in E.O. yield. The Antissa site on Lesvos Island is situated high on the mountain, has colder winters and milder summers, providing perfect conditions for Lavender cultivation.

The first harvest for commercial reasons should be performed in the second or third year of the plants’ life. Additionally, lavender for commercial use, as dried plant, must be harvested 10-15 days prior to the harvest for E.O. production. The best time for harvesting lavender for the production of E.O. is after full blooming, when half of the flowers have already withered. The stems should be cut 10-15cm below the flowers, which allows for better filling of the still, more spread out, allowing for even flow of the steam in the still and a better yield in E.O.

Climate and weather affect the yield of essential oil:

- a sunny day with mild weather and no wind must be chosen for harvesting.
- a potential rainfall at the day of the harvest (or even 2-3 days before), or the morning humidity on the leaves and flowers, will decrease the quality of the final product.
- extreme heat combined with strong winds will also favour the evaporation of essential oil, so a portion of the product will be lost if it is too hot and/or windy.

There are several harvesting techniques, depending on which part of the plant is needed and for what purpose. For essential oil production:

- only from flowers; producing higher quality essential oil
- both flower and leaves can be used, producing greater quantity, but lower quality

After harvesting, the plants are tied in bundles and hung up to be dried in the shade. This increases the oil content in the plant and leads to an increased essential oil yield. After drying the flowers are packed into boxes or cases lined with paper. It is best to dry the harvested plants for 1-2 days before distillation; this is valid for both lavender and oregano plants (Katsiotis and Chatzopoulou, 2010). The essential oil produced differs in quality and quantity from one season to the next, according to the weather and the age of the plants.

Table 2.2. Lavender E.O. yield

Lavender Spp.	Essential Oil Yield
L. angustifolia	1.4 – 1.6 %

Lavender is registered in all European Pharmacopoeias, in the US National Formulary, in the Monographs of Commission etc. Its main constituents are linalool, oxeic linalyl ester, camphor, 1,8 cineol. It also contains a variety of tannins, coumarins, flavonoids, phytosterols and triterpenes. It has been used since ancient times for its aromatic and healing purposes. It is demonstrating spasmolytic, antimicrobial, diuretic properties and is calming to the body and nervous system (Lis-Balchin *et al.* 1998). It is also prescribed for unease, insomnia, anorexia, nervous stomachic disorders, flatulence etc. It is also used widely in the perfume and beautification industries as well as in aromatherapy.

2.2.3. Melissa

Melissa is an endemic plant in Southern European areas, spread widely to the whole of Europe and met also in areas of Asia and Africa. In Greece it is growing wild almost everywhere on various altitudes. It is a perennial plant belonging to the family *Lamiaceae.* There are two subspecies of commercial value:

1) *Melissa officinalis spp. Officinalis* which is producing an essential oil rich in citronellal and α- and β-citral
2) *Melissa officinalis spp. Altissima* the essential oil of which is rich in β-caryophyllene, d-germacrene, and β-cubebin

Usually for essential oil production *Melissa officinalis spp. Officinalis* is cultivated. The plant likes to be in the shade and in a moist environment, but a soggy ground which withholds water should be avoided. It is sensitive to long winters, so areas which become warm in early spring are preferred. A field may yield production for up to 4-5 years. Harvest must be done before blooming; the tender tops are cut before becoming woody and long. The best time for harvest is late in the morning. The plants must be cut at a height of 10-15 cm from the ground, although producers focusing on A' quality leaves cut the plants at a height of 40 cm from the ground up. Great attention must be taken when handling the fresh cut plants, because the sun or any abrasion create black spots and darkening of the leaves, which deems them commercially unexploitable. During the first year after planting, only one harvest is performed, while in the next years two, or even three harvests can be done (1st mid-June, 2nd mid-August and 3rd beginning October). E.O. yields increase when the crops are planted on sunny, warm areas.

Table 2.3. Melissa E.O. yields

Plant Part	Essesntial Oil Yield
Fresh plant parts	0.01 – 0.03 %
Dry leaves	0.1 – 0.4 %

Melissa E.O. is colourless to slightly yellowish, with a characteristic lemon scent. It is practically non-soluble in water, but can be dissolved in ethanol, ether, chloroform, and fatty acids. It solidifies at +12°C. The E.O. yield is very low as seen above in the table and depends on the condition of the plant material, dry or fresh, while its quality is very much dependant on its geographical origin. It has been noticed that E.O. produced in the Mediterranean region have increased neral and geranial. The consistency is not only affected by climatic changes, but also from geological factors, the age of the plant, the time of the harvest

etc. It contains cotinellal (20-40%), citral (neral and geranial, 10-30%), β-caryophyllene and its oxides. The analogy of neral/geranial met in nature is 20/30. Storing conditions of the melissa E.O. are very important, as light, or oxidation can cause a change in the analogy given above, which in turn changes the quality and properties of the E.O.

Melissa is considered a medicinal plant. However, in central Europe it is often used in food for improving the smell in drinks, sweets, or cooked dishes. Leaves of melissa and E.O. are used to produce alcoholic beverages, in the perfume industry and in the pharmaceutical industry. In the latter one it is valued for its calming, antispasmodic, antibacterial, antiviral, antioxidant, antimicrobial and digestive properties (Katsiotis and Chatzopoulou, 2010).

2.2.4. Sage/Salvia

Salvia, or Sage is a perennial plant met on all mountain slopes of South Europe. It is widely used and cultivated for its pharmaceutical and healing actions, not only in Europe, but also the U.S, Malta, Canada and Argentina. It is a woody, small, up to 40-80 cm, bush with violet-blue, pink, or white flowers. The E.O. is mostly found on its relatively thick, hairy aromatic leaves. It prefers rocky, dry areas and an altitude of 0-300 m. The drier the climate, the greyer the colour of the leaves. It blooms at late spring from April until June. There are more than 700 varieties of salvia, with the Dalmatian *Salvia officinalis* producing the highest yields of E.O.

During the first year, only one harvest is performed, normally from August to September. During its second year, two harvests can be performed, one in the beginning of June and the second one in September. However, if the crop is regularly irrigated, the possibility for a third crop is quite high. It is advised that the harvest takes place during the midday-early afternoon hours, and the plants are cut 10-20 cm above ground. The harvest is performed at the beginning of the flowering period, as the oils are concentrated in the leaves. The yield of the first harvest (June) is often poorer in comparison to that of the second one (September). Moreover, as in all other aromatic plant crops, the yield is affected by several factors, such as climate, fertilizer application and irrigation. As stated above the leaves of Salvia are the parts of the plant that are of interest. These can be separated by hand or tools while the plant is still fresh, or even when it has dried, in which case it is difficult to receive whole leaves.

According to the European Pharmacopoeia, the plant material must be in its majority leaves (up to 2% of other plant parts), which in turn must contain at least 20ml E.O./kg, with a maximum of 30 ml/kg. The E.O. contains a variety of constituents: monoterpene ketones such as camphor and α- & β-thujone; monoterpene hydrocarbons, such as camphene, sabinene, cis-ocimene, trans- ocimene, terpinolene and others; oxygenated terpenes (1,8 Cineol); sesquiterpenes (caryophyllene); monoterpene alcohols, such as linalool, borneol and others; esters (oxeic bornyl). Amongst the above, the most important ones are 1-8 cineol, β-thujone and camphor. These constitute 30-60% of the essential oil. Thujone exhibits slight toxicity and may be up to 50% of the E.O., therefore, oral intake of the salvia E.O. is not recommended. Sage/Salvia has been used as a spice and as herbal remedy since ancient times. It is used as a food additive to provide improved aroma and taste with the prerequisite that the Thujone content is up to 0,5 mg/kg (Katsiotis and Chatzopoulou, 2010). As herbal remedy it has been proven to have a variety of actions, amongst them antispasmodic, styptic, sweating, antiseptic (Barnes *et al.* 2002), antibacterial, antimycotic, antioxidant, anti-inflammatory. Salvia E.O. is widely used in the food industry as a preservative, or for the production of beverages, in the perfume and cosmetic industries, as an insect repellent, as an odour and taste improving agent in chewing gum, or as an additive in mouth washes due to its anti-inflammatory action.

Table 2.4. Salvia E.O. yields

Plant Part	Essential Oil Yield
Dry leaves	1 – 3.5 %

2.3. Distillation Methods and Distillers

There are three types of distillation:

1) Water distillation
2) Water/steam distillation
3) Steam distillation

1) Water distillation

This type of distillation is characterised by the fact that the plant biomass is in contact with the water being heated and is boiling. Depending on the plant material, it is floating on the surface, or it is immersed into the water. This method is used for almond grinds, rose pedals, orange blossoms and all other materials which must be able to move freely during distillation and could not be steam distilled as they would coagulate into solid lumps non-penetrable from the steam. In water distillation the following points can be considered:

- Ensure to fill the still correctly
- The plant biomass must be covered with water
- Monitor the distillation rate
- Avoid overheating the plant material
- Apply a simple, economic, and easy-to-use method
- They are often used as home distillation method
- The process requires long distillation times and yields often lower quality E.O.
- The still should be short, but with a wide diameter

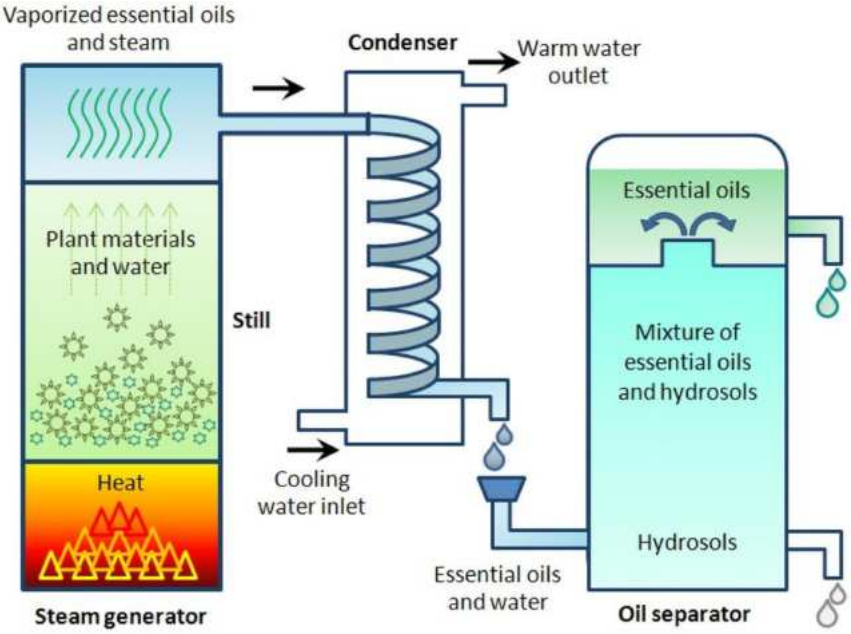

Figure 2.1 : Diagram of a Water Distillation Unit (source: Journal of Food Science Vol. 79, Nr. 7, 2014)

2) Water/steam distillation

In this type of distillation, the water does not encounter the plant biomass. A net is placed a little bit higher from the surface of the water separating the biomass. This way the distillation occurs by the steam produced by the boiling water at the bottom of the still. This steam is saturated, moist and of low pressure. This method protects the plant biomass from overheating and from coming in contact with the water. This method:

- Is a simple method
- Is used for smaller scale distillations
- Has longer distillation times
- Yields smaller quantities of E.O. comparing to the steam distillation
- Requires "stacking" of the material in the still to avoid steam channels building and thus reducing the E.O. yield, due to low steam distribution

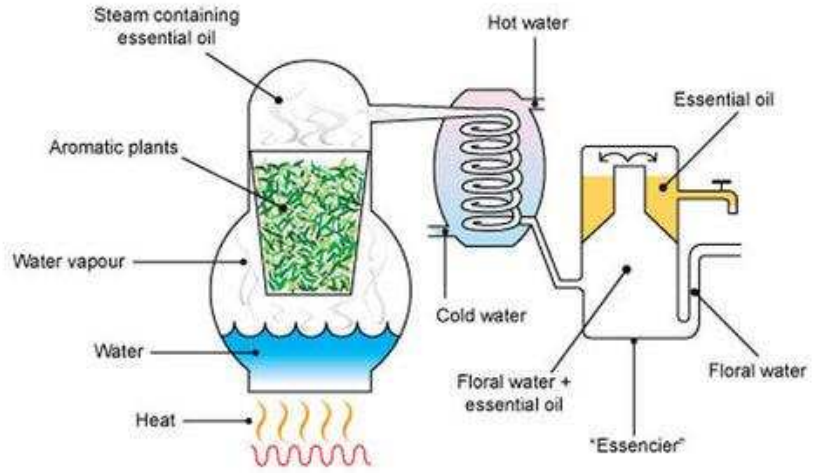

Figure 2.2 Diagram of water/steam distillation (source: SCRIBD Isolation of Menthol)

3) Steam distillation

This is the type of distillation used for industrial production of E.O. Large stills for 2-3 tons of plant material are used. There is no water present, only pressurised steam is released in the still. At the bottom of the still there is a valve for this purpose, releasing steam inside through a perforated floor for better distribution through the plant material. This method:

- The steam pressure should be monitored based on the relevant calculations according to the plant material, quality and quantity.
- Yields better quality E.O.
- Has greater yield
- Requires an extra steam generator and large distiller units, which are difficult to handle - the steam can overheat the material
- Also requires "stacking" of the material to avoid steam channels building and thus reducing the E.O. yield, due to low steam distribution

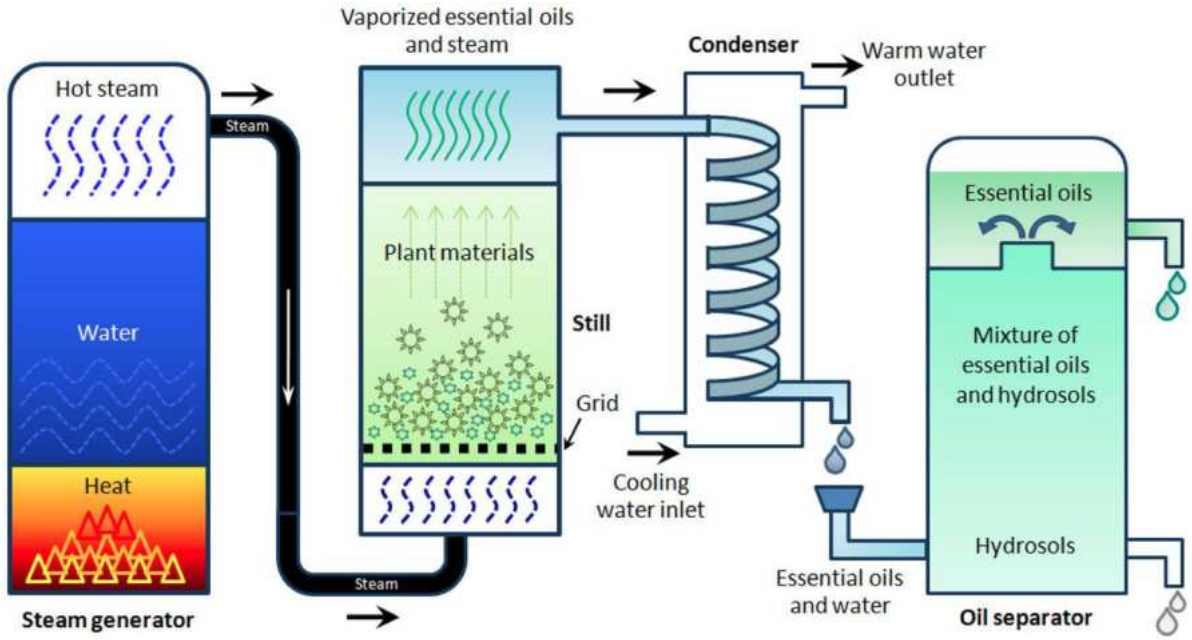

Figure 2.3 Diagram of Steam Distillation (Source Journal of Food Science - Vol 79, Nr 7, 2014)

In all types of distillation stated above, the operator should always consider and monitor the following factors:

- The capacity, materials and shape of the still
- The plant mass to be distilled, which also determines the distillation time
- The quantity of the plant biomass and the way it is stacked in the still
- The distillation speed, which is influenced by the amount of heating, or steam provided and the speed of cooling
- Any prior processing of the plant material, which could cause other phenomena affecting distillation. Such phenomena are:
  - Hydrolysis
  - Disintegration
  - Diffusion by water

The distillation type determines the type of the distiller unit. There are three types of distillation units:

I. Water distiller
II. Water/steam distiller
III. Steam distiller

Often water/steam distillers can perform water distillation as well by removing the separating sieve, or basket and emerging the plant biomass in the water. The most appropriate methods for distilling the plants produced at the HYDROs are proven to be water/steam distillation and steam distillation, by using the equivalent distillers.

2.4. Home and Commercial Production

For home, small to medium distillations, or for mobile distillation units the choice of water or water/steam distillation is preferred, because of the simpler construction of the equipment. This gives the advantage of a more cost-effective method, usually faster, which often provides a better yield and good quality of E.O. In the case of large scale, industrial distillation units, where tons of plant biomass are being distilled, steam distillation units provide better results. Several parameters are being monitored and tuned (steam

pressure and temperature etc.) according to the needs of the plant biomass and species destined for distillation, yielding optimal results.

The demo sites on Mykonos and Tinos belong in the category of home (ELT) and small (DEL) distiller units. The amount of plant biomass produced at each site and the purpose of use of the distillers, were the two major factors leading to the conclusion that ELT would require a home distiller, less than 70 L and DEL would require a small/medium size professional distiller. DEL has chosen a 300 L stainless still model, while ELT a 40 L copper unit.

2.5. Sellers and Manufacturers

ALCNGR proceeded to conducting market research for distiller manufacturers in Greece. After a second meeting in November 2021 with the task partners, this list was shared and other manufacturers from within the EU were added. ELT and DEL proceeded to contacting the manufacturers, requesting details for sizes, prices etc. The orders were placed after internal communication. DEL has chosen to order a custom-made unit, constructed in Greece and reached the final decision after consulting with the manufacturer. ELT has chosen to order the distiller from a well-known manufacturer in Portugal, to ensure a good quality product, as in this case the distiller would be made of copper and required specialised craftmanship.

2.6. Legal Framework for Possession of Distillers in Greece

2.6.1. Professional distilling units

Customs authorities are defined as the competent authorities for the implementation of the regulations regarding the possession of distillers in Greece. It is authorised and works in coordination with the General Directorate of Customs, the E.F.K., the Chemical Services of the General Chemistry of State and the Independent Public Revenue Authority.

Distillation units are listed in the registries of the General Directorate of Customs and Excise Taxes, General Register of Possession of Distillation Machinery and have their protocol Number engraved on them by the General Registry both on the boiler and on their cover. Issuing a license for a professional distiller unit has become more difficult during the last decade, due to the restrictions and increased controls for illegal alcohol home-distilling.
For those who wish to proceed and acquire a professional distilling unit, a possession permit is issued by the Customs Office responsible for their area of activities. On this permit a detailed design specifying the parts of the distiller, the exact shape and its characteristic measurements and components is attached. The Customs Office in charge of the jurisdiction where the business/person ordering the distiller is registered, issues a construction permit. This permit is notified both to the coppersmith, or craftsman who has received the order for the distiller production and to the Customs Office in which territorial jurisdiction the coppersmith belongs, i.e., the distiller construction facility, if it is in a different area. In addition, the competent Chemical Service under which Jurisdiction the distillation unit falls is also notified, with a copy of the relevant application and the submitted blueprint.

The distillation unit remains permanently sealed when the distiller is not used. It is unsealed by the competent customs authority only for a short period for which a distillation license has been issued. During this process, the condition of the seals is checked, according to the relevant sealing protocol.

Sealing of the distillation unit must be carried out immediately after the completion of distillation, or of all the distillations for which distillation licenses have been issued with use of the particular still, during the respective distillation period. This must be done by the owner, who is issuing a statement, the latest

on the next working day from the end of the distillation works. This statement must declare the imminent end of the distillation operations and request the sealing of the distillation unit.

All licenses and permits must be issued in the name of the person/business ordering the distiller. For simplicity and transparency purposes it was decided that the purchase of the professional distiller for the demo site on Mykonos Island, DEL will be responsible for licencing and ordering.

2.6.2. Home/non-professional distillers

All distillers up to 70 L are considered non-professionals, or home distillers. In Greece, the ownership of a professional distiller unit is nowadays strictly controlled as explained above. However, the legislation for the possession of a non-professional distiller is not clear. In fact, non-professional distillers (below 70 L) are omitted from the legislation, and they are not taken into consideration. A permit is not necessary for their possession and use; however, it might become in the future. For this reason, it was decided that ELT will take the responsibility of purchasing the distiller, invoicing it in their name, in order to be able to start the permit issuing process if they are asked to, or if the legislation changes.

2.7. Workshop

ALCNGR organised an open workshop at each of the two demo sites in July 2022. The purpose of the workshop was to introduce and guide the two demo site leaders, ELT and DEL, in the process of distillation, and demonstrate potential further uses of the E.O. and hydrosols produced.
Workshop Program:

- Distillation process practical workshop and theory (4 hours)
  - Preparing material
  - Preparing distiller
  - Making essential oils and Hydrolat/Hydrosol
  - Distilling essential oils from Mediterranean aromatic plants theory/presentation (technical issues, quality control, production specifications for different plants)
- Investing on essential oils (3 hours)
  - Uses of essential oils
  - Essential oil blends and recipes
  - Marketing essential oils
  - Practical workshop:
    - Oil blends
    - Making a face and body cream with natural ingredients, essential oils and hydrosols.

ALCNGR prepared a list with all the necessary additional lab materials, equipment, and constituents to be purchased from the two partners for the storage of the E.O. and hydrosols, but also for the production and packaging of the creams, lotions etc. to be produced during the workshop and after that in future ones. The workshop on Mykonos took place on the 3rd of July and the 10th of September 2022. The reason for this was that the distiller, while tested after installation, presented a problem and a spare part was ordered for replacement. Therefore, all the distillation process content was given initially in theory, the presentations and the theoretical aspect were presented as planned. Furthermore, the practical workshop for cream/ointment preparation was conducted with one more participant. A second workshop day was planned to take place after the repair of the distiller was completed. On the 10th of September the practical distillation part of the workshop took place, with the contribution of five additional participants.
In addition, a second workshop was later planned for the visit day (June 10th, 2023) of the Water Innovation and Circularity Conference (WICC). During that day, demonstration distillations were

performed and the resulting E.O. and hydrosols were used for the formulation of soaps and creams by the participants.

Figure 2.4 Cream formulation at DEL

The workshop on Tinos Island took place according to plan on the 6th of July, with a total number of 12 participants.

Figure 2.5 Installation and distillation at ELT

3. ESSENTIAL OILS PRODUCTION ON MYKONOS ISLAND

3.1. Introduction

On Mykonos Island, two HYDRO systems are implemented i.e., HYDRO3 and HYDRO4. These two systems collect and store rainwater and use this water for irrigation. The climatic conditions on Mykonos Island are dominated by hot and dry weather most of the summertime and mild temperatures with a short rain season during winter. In addition, Mykonos Island is highly touristic and therefore, the type of crops to be cultivated (keeping in mind the water quantity and quality of HYDRO3 and HYDRO4) should be chosen according to the above stated parameters.

Oregano and lavender are two dry soil crops cultivated for the use of their "high value" essential oils and hydrosols. Oregano has been used for centuries for a variety of its health improving properties. It contains multiple antibacterial and antimicrobial properties. It has been used to relieve coughs, reduce body odour, soothe digestive muscles, and lower blood pressure. It is a strong antioxidant, with high levels of beneficial acids and flavonoids. Lavender is a perennial plant that can live up to 20 years if the conditions are optimum. It produces purple flowers, which contain high levels of essential oils. Mediterranean countries (Italy, France, and Spain) have a long tradition in growing lavender. Nowadays, countries such as USA, Canada, Japan, Australia, and New Zealand are also considerable commercial lavender producers. The essential oil of lavender is recognized globally as a respected commodity. It has several medicinal properties, such as remarkable antiseptic and antimicrobial action, as well as other uses.

HYDRO3 and HYDRO4 covers about 0.4 ha and 0.2 ha of land area, respectively. The highly touristic nature of Mykonos Island is definitely a very important factor for the setup of the HYDRO systems, a factor that also influenced the choice of plants to be cultivated there. As hotels and resorts situated on the island are high consumers of the freshwater resources with a high amount of water being imported to the island, it deems the use of fresh water in agriculture a challenge. Therefore, these two HYDRO systems depend on rainwater harvesting/collecting systems and use of these reserves for the cultivation of plants (in mono-farming system), providing an added value to the island.

3.2. Preparatory actions

3.2.1. On the Oregano field

- Recovered rainwater is used for the irrigation of the oregano field since the summer of 2020. The plant chosen was *Origanum v. Grazile L*.
- 10.000 seedlings were ordered and planted in December 2019 and parts of the cultivation were re-planted in 2021 and 2023 (for more details see Deliverable 4.5: Report on yields, health of crops and derived products)

3.2.2. On the Lavender field

- 6,000 plants of *Lavandula angustifolia* were ordered in autumn 2020, planting was delayed due to COVID-19 restriction, so was planted in spring 2021, but was lost, dried out. 6000 new plants were planted in autumn 2021 and replantation took place when needed (for more details see Deliverable 4.5: Report on yields, health of crops and derived products)

After harvesting, the plants are dried in the shade. A 25-cm stack height is preferred during drying operations in order to facilitate the accumulation of etheric oil content. Natural drying is a common procedure for Origanum, or else oven drying procedure is recommended at 30-35°C in commercial scale

production. A moisture content of 7% (minimum) to 12% (maximum) is required. The separation of dried leaves and spike-like inflorescences from stems is done by hand when the same quantity of material is involved (in large production, threshing machines are used). Combined threshing machines are usually preferred. Since volatile oil percentage gradually decreases after 4-5 months of storage; it should be kept in conditions of cool and relatively low humidity.

Figure 3.2 Lavender harvested at DEL

Figure 3.1 Lavender tied in Bundles at DEL

3.2.3. Permits

Following the procedure stated above, all necessary actions were performed, the construction permit was issued, and the order of the distiller was placed. The License for constructing, repairing, transporting distilling equipment issued for DEL is included in the Annex session.

A transport permit was required for the transport of the constructed parts of the distillation unit. This permit is granted by the competent Customs and accompanies the machine. The Customs Office, based

on the details of the application, defines in this permit the required period of time for the transport of the distillation unit to and from the place of installation. This permit is also notified to the Customs Office in the area of the coppersmith. This is done for both Customs Offices to be informed about the current position of the distiller, and to avoid problems and misunderstandings in case the distiller is damaged, needs to be repaired and finds its way back to the coppersmith, who could be charged with illegal manufacturing if a control at his facilities happens. When there is a need for repairs the relevant Customs Office needs to issue a repair permit escorting the distiller, and the Customs Office in the area of the Coppersmith needs to be notified as well.

After the completion of the construction, the distillation unit was transported to Mykonos accompanied by the above transport permit as well as a declaration issued by the artisan/coppersmith. In the latter one, the date of completion of the necessary work, the date of commencement of the transfer of the distillation unit are stated. In addition, the coppersmith states that no change has occurred in the geometric elements of the distillation unit, as well as that the materials used, in terms of their suitability, meeting the conditions of the applicable legislation regarding the materials and objects in contact with food. The official documents used for the licence permission are included in the Annex section (the official declaration of material used by the coppersmith. The declaration of compliance of the manufacturer, the test certificate of the materials, the certificate of analysis of the material used for the distiller, the license issued for the transport of the distilling equipment) as well as the final distillation permit.

DEL, according to the procedure, informed the Customs and Chemical Service in the territorial jurisdiction of which it is registered, within a period of five (5) days from receiving the distiller. After that, the Chemical Service visited and controlled the premises and issued a new certificate of suitability for the distillation unit. The relevant Customs Office, after the completion of the above checks and the grant of the certificate of suitability from the competent Chemical Service, visited the premises and proceeded to the sealing of the distillation unit according to the law.

3.3. Ordering and Purchase

The order of the 300 L Essential Oil Distiller (steam distillation) was done in July 2021 and it was finally received it in February 2022.

It consists of:

1) The still
A large cylindrical still resting on 3 legs on the ground (with the possibility of plugging). It is double walled and insulated. The double wall contains oil which is heated by a resistance 3x4 kW / 380 Volt (1 piece) accompanied by an analogue thermostat measuring 0-150^{o}C, integrated within a box /panel resting on the side of the still. It has an analogue thermometer 0-200°C for providing a temperature level indicator for the heated oil in the double wall of the still. One expansion and one suction valves, i.e., ½¨ outlet and inlet valves for the heated oil in the double wall are also present. In the upper part it has circumferential tightening keys used to fix and tighten the cone shaped lid. The lid carries the sealing flange and on the top the thermometer, measuring 0-120°C for the steam created inside the still.

2) Bow
A stainless-steel tube Φ40X1.5mm with DN 40 AND DN 20 fittings at its ends for connecting (bridging) the still with the refrigerator for condensation of the steam produced by distilling the aromatic plants.

3) Refrigerator / Condenser

Stainless steel closed type condenser, with coil, it has the cooling water inlet at the bottom (1/2" valve) and the warm water outlet at the top (¾" valve). On the front side there are two thermometers measuring 0-120°C. One that measures the temperature of the cooling water as it enters and one which measures the temperature of the warm water as it exits.

4) Separator / Florentine Flask

Stainless steel separator with glass Φ100 outside/90mm inside, with ½¨ stainless steel valve for receiving the essential oil and a 3/8¨ stainless steel valve for communicating with the cone inside the glass.

Figure 3.3 The distiller at DEL

3.4. Installation

- The still was connected to the condenser by installing the bow.
- The Florentine flask was placed at the base of the refrigerator.
- The hydraulic connection of water to the refrigerator was made by a plumber, by optionally placing an electric valve at the bottom of the refrigerator.
- The power connection was made by a certified electrician.

With this distillation unit DEL has the possibility to perform two types of distillation:

Water/Steam Distillation

- The tripod is placed in the still and the perforated screen on top.
- The still is filled with water up to the point where the sieve starts.
- Then aromatic plants are placed in the sieve, taking care to spread them evenly, to avoid steam corridors building up.
- The plant material is press slightly and more is added.

Water Distillation

- The sieve is placed at the bottom of the still by removing the tripod.
- The distiller is filled to the top with water and plant mass in a ratio of 3 parts water to 1 part of plant.

Concluding the process

- Using the keys and temperature gloves the lid is released.
- The lid is removed with gloves.
- The perforated screen containing the plant material is lifted up with a small crane.
- Water is added to continue with the next distillation, or the remaining water is emptied by opening the bottom valve if the process is finished.

3.5. Workshop

On the 3rd of July 2022 a workshop was planned by ALCNGR. The workshop was planned to last 2 days. Its purpose was to guide DEL through the steps of the distillation process, performing a first distillation in the first day, and the second day use the distillation products for formulating creams and lotions and demonstrating further uses of the essential oils and hydrosols produced. However, the distiller presented a technical problem on the 3rd of July. Therefore, every theoretical part of the program was completed on that day and creams were prepared.


Figure 3.4 Formulation of Beeswax Oregano ointment at DEL, July 2022

At the beginning of September 2022, the spare part was received. After changing the malfunctioning part of the distiller, a second workshop date was set. On the 11th of September 2022 the technical workshop was completed, and the first distillations were performed. For carrying out this task 5 external participants contributed by offering their assistance.

Figure 3.5 Distillation at DEL, Sept. 2022

3.6. Production

Following the completion of the workshop in 2022, DEL applied the acquired knowledge to conduct distillation on the remaining Oregano harvest. The two separate Oregano crops from 2021 and 2022 were distilled individually. The resulting essential oils (E.O.) were carefully bottled in small, convenient 5 mL dark glass containers, equipped with a pipette for easy usage. Similarly, the hydrosol was bottled in 50 mL and 100 mL dark glass bottles. In June 2023, further distillation took place, encompassing both lavender and oregano production. The detailed yields from these distillation processes are provided in Table 3.1.

A noteworthy event occurred on the 10th of June 2023 when an additional distillation operation coincided with the visit of participants from the Water Innovation and Circularity Conference (WICC). On this occasion, 58 kg of oregano, sourced from the Lesvos site, underwent distillation, resulting in the production of 286 ml of essential oil and 5.5 L of hydrosol. So, as part of the WICC visit, during their guided tour on the Nature-Based Solutions (NBS) implemented in two of our demos (HYDRO4 residential rainwater harvesting and HYDRO3-subsurface rainwater harvesting), visitors had the opportunity to receive a briefing on the distillation process and take part in a small workshop focused on soap and cream production (Figure 3.6). In this workshop, participants had the opportunity to use the E.O. and hydrosols produced earlier that day for the formulation of soaps and creams. As a result, bars of lavender, oregano and mixed soaps were produced, as well as Galenic creams which were then stored in dark 100ml glass jars (Figure 3.6). In total 8 kg of soap were produced in 150mg bars. 8 kg were produced using the cold method of which 2 kg were then cured using the warm method.

Table 3.1 E.O. Yields for HYDROs 3&4

	2022			2023		
	Plant yield (kg)	Essential oil (ml)	Hydrosol (L)	Plant yield (kg)	Essential oil (ml)	Hydrosol (L)
lavender	17.5	180	2	105	1100	11
oregano	135	980	9	330	2500	26
Oregano*				58	286	5.5

*Oregano harvested in HYDRO2 and distilled by DEL on Mykonos for the WICC conference

Figure 3.6. Demo site visit in Mykonos (HYDRO3&4) of the WICC participants and small workshop of essential oil and soap production.

3.7. Lab analysis

In the following Tables the results of the essential oil lab analysis are presented. From these results it can be noted that a high percentage of γ-terpinene in relation to the percentage of carvacrol was found, which means that the plant could yield even more E.O. if the harvest was done towards the end of June and the beginning of July. The consistency of the oregano E.O. depends a lot on the period of harvest and the species, but also on the plant year, as it is reported that after 3 year of cultivation the essential oil reach the higher production yield but also the best quality possible. Further discussion on the analysis results is presented in section 6.2.

Table 3.2. Analysis results of oregano E. O. produced in 2021

Compound	% yield	Compound	% yield
Alpha- Thujene	1.42	Gamma-Terpinene	15.48
Alpha-Pinene	2.48	Cis-Sabinene hydrate	0.28
Camphene	0.85	Alpha-Terpinolene	0.29
Beta-Pinene	0.37	Trans-Sabinene hydrate	0.09
1-Octen-3-ol	0.82	Borneol	0.52
3-Octanone	0.28	Terpinen-4-ol	0.55
Myrcene	4.18	Carvacrol methyl ether	0.59
Alpha-Phellandrene	0.48	Thymol	2.35
Delta-3-Carene	0.20	Carvacrol	32.31
Alpha-Terpinene	3.61	Beta-Caryophyllene	2.16

p-Cymene	27.65	Alpha-Humulene	0.04
Limonene	0.61	Trans-Beta-Farnesene	0.21
Beta-Phellandere	0.46	D-Germacrene	0.04
1,8-Cineol	0.07	Beta-Bisabolene	0.60
Cis-beta-Ocimene	0.25	Delta-Cadinene	0.07
Trans-Beta-Ocimene	0.11	Caryophyllene oxide	0.06

Table 3.3 Analysis results of oregano E.O. produced in 2022

Compound	% yield	Compound	% yield
Alpha- Thujene	2.21	Gamma-Terpinene	12.88
Alpha-Pinene	1.73	Cis-Sabinene hydrate	0.34
Camphene	0.54	Alpha-Terpinolene	0.29
Sabinene	0.03	Trans-Sabinene hydrate	0.14
Beta-Pinene	0.36	Borneol	0.58
1-Octen-3-ol	0.83	Terpinen-4-ol	0.70
3-Octanone	0.26	Carvacrol methyl ether	0.65
Myrcene	3.70	Thymol	2.71
Alpha-Phellandrene	0.48	Carvacrol	41.76
Delta-3-Carene	0.17	Beta-Caryophyllene	2.26
Alpha-Terpinene	3.13	Alpha-Humulene	0.09
p-Cymene	21.28	Trans-Beta-Farnesene	0.23
Limonene	0.51	D-Germacrene	0.04
Beta-Phellandere	0.47	Beta-Bisabolene	0.59
1,8-Cineol	0.07	Delta-Cadinene	0.07
Cis-beta-Ocimene	0.13	Caryophyllene oxide	0.08
Trans-Beta-Ocimene	0.10		

3.8. Valorisation

Mykonos Island is a very popular destination for tourism. The island is equipped and provides facilities for every taste, on all price levels. Apart from beautiful beaches and entertainment, Mykonos is a destination that can combines wellness, sports and active holidays, conferences and team building with a wonderful culinary experience and beautiful nature. There are many luxury villa resorts with marine therapy pools, wellness centres, spa culinary cuisine in which holistic programs are conducted, with individual approaches and modern equipment that provide aid to all that wish to achieve unity of mind and body. Health Tourism is also developing rapidly in line with the trends in the tourism market. The latter one is at the moment divided in three categories: health tourism, medical tourism and wellness tourism. Each category is specific and develops according to the needs of the market.

Sustainability is a very strong factor and pre-requisite which accompanies the latest trends in the tourism branch. Green-, Eco-, Sustainable-, Agro-tourism: holidays with respect to and in harmony with nature are on the rise, which also leads to a rise in environmental consciousness and provides for a strong shift towards comprehensive green practices, from the use of natural ingredients in treatments and nutrition, through the use of natural materials for lighting or ventilation, for decoration of the premises, or environmentally responsible management of energy, water, and waste at the level of facilities and whole destinations.

At the Mykonos demo site, essential oils and hydrosols are produced in a sustainable and innovative way, while in parallel, the local health/wellness market is flourishing, providing a unique business opportunity

for the products created in the HYDROUSA project. Thus, the distribution of the final products in the local market is a successful idea with fast, positive results in terms of advertising, recognition, cost reduction and promotion in the local community. For this purpose, packages were made as promotion samples and given to touristic units/businesses to use for various purposes. Oregano oil was packaged in the form of sprinkles to be used in restaurant kitchens, or olive oil aromatisation and used by beauticians in hotel spas. Lavender oil and hydrosol where also promoted for use in spas to aromatise massage oils, as well as bath water and gift packaging. Some examples of the oils, hydrosols and creams produced at the workshop were shown at the HYDROUSA conference on Lesvos Island in September 2022 (Figure 3.7) and in several exhibitions and events (Figure 3.8).

Figure 3.7 E.O., Hydrosols and ointments produced at DEL, at the IX consortium meeting Lesvos

Figure 3.8. HYDROUSA's added value products exhibited in WICConference in Athens, 2023 (left) and in the Festival of the New European Bauhaus in Brussels, 2022 (right)

4. ESSENTIAL OILS PRODUCTION ON TINOS ISLAND

4.1. Introduction

In HYDRO6 at ELT, a part of the land, approximately 470 m^2 is dedicated to the production of aromatic plants. The initial variety of planted aromatic plants was high, in order to test adaptability and crop yields to local conditions and create a natural herb garden surrounding the periphery of the guest houses. Initially, ten different varieties of herbs were planted: sage, thyme, lavender, rosemary, St. John's wort (*Hypericum* sp.), oregano, savoury, immortelle (*Helichrysum sp.*), and dittany (*Dictamnus albus)*. These plants were (and some of them still are) produced for in-house and local consumption during the tourist season from April until October. The plants are dried and stored. They are offered to the clients of the facilities, presented in baskets, for culinary, aromatic, or infusion-making purposes. Moreover, a percentage of oregano, thyme and lemon thyme are promoted to local restaurants.

ELT wished to offer workshops for locals and tourists, showing them the distillation process and ways of formulating creams, lotions, ointments using the E.O.s and hydrosols produced during the workshop. These products, namely the E.O.s, hydrosols and additional formulations would then be offered to the participants and the customers of the Ecolodge.

4.2. Preparatory actions

The final overall development of the herb plantation at HYDRO6 is satisfactory. From the initial wide variety of herbs that were planted to observe their adaptation to the local conditions the oregano varieties, rosemary varieties, lavender, thyme and dittany proved to be the most resilient and productive within the given setting.

The immortelle suffered greatly from a fungus infecting their root system network, causing them to dry out. A lot of efforts were made by adding organic fungicides to the soil and some plants were indeed salvaged. Immortelle appeared to be the most vulnerable to the root system fungus, even after treatment, the whole plantation was lost, a great percentage of the sage planted also dried out, leaving only a fraction after the treatment intact. The oregano and lavender crops were affected only to a small extend, thus they were considered the best candidates for distillation. Many plants were replanted during the third year, in an attempt to recover the initial planned numbers and others were replaced by more resilient and productive species. The plants were harvested either by hand or by mechanical means. After harvest they were hanged to dry in room temperature, in a dry, dark room.

Permits

As stated above a small, home distiller was chosen to fulfil the needs of ELT. A permit for a home distiller was not required. However, as stated above as well, ELT has claimed ownership of the distiller and the order, to initiate a licencing process if this in the future is deemed necessary, or if there is a change in the current legislation.

Figure 4.1 Harvesting Lavender

Figure 4.2 Lavender

Figure 4.3 Aromatic plants at ELT

4.3. Ordering, Purchase, Installation

ELT has chosen to order a small 40 L copper distiller. As the distiller at ELT serves an educative and promotional purpose, copper was chosen as the preferred material. The decorative effect of the unit and the beauty/design of the material in relation to the facilities was also considered. The distiller arrived at Tinos in November 2021 after the tourist season had ended. Thus, it remained stored until June 2022. In June 2022 ELT offered the first educational workshop on E.O. distillation, where the distiller was also installed for the first time.

Figure 4.4. Arrival of the distiller parts at ELT

Figure 4.5. Assembling the distiller unit

4.4. Workshop

In total, ELT has offered 3 workshops on distillation for E.O. and hydrosol production. The first one was on the 8th of June 2022 with the guidance of a local distiller, Thierry Veiron. This was organised by ELT for an initial introduction of the distillation process to the Ecolodge team with 5 participants. The second one on

the 6th of July 2022 was organised by ALCNGR as an open workshop, where locals could also freely participate. This workshop was conducted with 8 participants. The third one was offered as part of the permaculture workshop on 1st of October 2022 with 12 participants. ELT performed this without external guidance.

During the three workshops, five distillations were performed: three with Lavender and two with Oregano. The first two times 1.5 kg of dried Lavender plant biomass was distilled, which resulted to 10 mL E.O. and 1 L hydrosol; and 1 kg of Oregano dried plant biomass, which yielded 30 mL E.O. each time. The Lavender hydrosol and E.O was used to produce creams during the July HYDROUSA workshop and the October permaculture workshop. In total 12 x 50 mL glass jars and 24 x 25 mL glass jars of face cream were produced. These were offered to the residents of ELT. In addition, in Summer 2021, the Helichrysum was salvaged due to the fungal infection, was dried and given to a local distillation unit to be distilled. The quantity was very small (300gr), yielding a small amount of E.O. and 2 L of hydrosol, which was then used for formulating a mosquito repellent. This was also offered to the residents of ELT.

Figure 4.6. Essential oil distillation workshop at ELT

Table 4.1 Aromatic Crops & E.O. production per Year in HYDRO6

Year	Lavender (kg)	Oregano (kg)	E.O. (mL)	Hydrosol (L)
2022	2	4.5	60	10
2023	45.3	10.5	460	38

4.5. Valorisation

At ELT the distiller is being used for small scale essential oil production from plants produced and watered by rain catchment systems on the land. Participants aim to use this knowledge mainly for educational purposes, offering workshops to guests and visitors of Tinos Ecolodge. The E.O. and hydrosols produced are offered to the guests and are formulated into lotions, creams, ointments which are also offered to the guests as welcoming gifts, adding an extra value to the facilities and the services provided.

Figure 4.7 Lavender Hydrosol and other products at ELT

The extra value created for ELT lies in the additional offer for their guests. The already developed workshop programmes (for permaculture) can be enriched with distillation and cosmetics production courses. This can potentially also be booked separately for example for €30-50 per person for a half-day workshop. Holding these workshops would probably make more sense, if 4 or more people come together. In addition, the developed cosmetics can directly be used on site for the guests, which can on the one hand be used for additional marketing (self-sufficiency, green, etc.) and on the other for increasing independency from bought products which usually also come in small plastic bottles.

5. ESSENTIAL OIL PRODUCTION ON LESVOS ISLAND

5.1. Introduction

HYDRO2 is an agroforestry system with a wide diversity of trees, shrubs, aromatic plants, and annual crops. The species were selected during a dedicated co-creation workshop with local farmers and citizens in Lesvos Island and with the ethnobotanical study that was conducted specifically for this area. The results of the workshop, the study and the selection of plants are included in Deliverable 4.3. The agroforestry includes more than 60 different plant species with a variety of aromatic plants like lavender, oregano, rosemary, sage, mint, thyme, melissa, savoury, *Cistus*, *Echinacea* sp., pelargonium, and calendula. During the first year it was decided to support the plants growth without risking an immature harvesting that could negatively affect the plants long term performance. Some minor pruning was implemented during September 2021 mainly in lavender and oregano.

Figure 5.1 Oregano at HYDRO2

Figure 5.1 Lavender at HYDRO2

5.2. Essential oil distillation trial 2022

During a trial harvesting procedure during late September 2022, about 473 kg in terms of green leaves/flowers of lavender, oregano, sage and melissa were collected. The harvested aromatic plants were then sent to a local distillery lab on Lesvos Island to produce essential oil and hydrosol.

Figure 5.2. Harvest for distillation on Lesvos HYDRO2

It was decided to test the production of a small quantity of essential oils and hydrosols from some of our aromatic plants to evaluate possibilities and yields. Essential oil was extracted as main product during the distillation process (Table 5.1) and high quantities of hydrosol distillation.

Figure 5.3 The E.O. produced by HYDRO2

Figure 5.4 Pruning of lavender plants

The second trial for essential oil production from aromatic plants cultivated in HYDRO2 took place during May-June 2023. The pruning of flowers and leaves from sage was conducted during late May while the harvesting of oregano, lavender and Rosemary started during middle May and was concluded during late June 2023. The harvesting was conducted by the HYDRO2 personnel, and the plants were transferred the same day to a local distillery lab in Mytilene.

Figure 5.5. Pruning of sage plants

The total harvested mass of aromatic plants was equal to 1677 Kg and the total essential oil production was up to 5.82L. About 123.5L of hydrosol was also produced as presented in Table 5.1.

Figure 5.6. Transferring of lavender plants for distillation.

Figure 5.7. Essential oil (left) and hydrosol (right) produced in HYDRO2

Table 5.1. Aromatic Crops & E.O. production per Year HYDRO2

year	Product	Oregano		Sage		Lavender		Rosemary		Melissa	
2022	Essential oil	130.6 kg	295 mL	95.5 kg	140 mL	200 kg	202 mL	-	-	47 kg	-
	Hydrosol		8 L		10 L		22.5 L		-		5 L
2023	Essential oil	195 kg	438 mL	151 kg	60 mL	550 kg	3.3 L	250 kg	1.1 L	-	-
	Hydrosol		14.5 L		4 L		42 L		12 L		-

**In 2023, extra 58 kg of oregano was distilled by DEL in Mykonos within the WICC workshop, producing 286ml essential oil and 5.5L hydrosol that is not included in this Table.*

5.3. Lab Analysis

Samples of oregano, lavender and rosemary were sent for analysis. Discussion on the analysis results is presented in section 6.2 below.

Table 5.2 Results of rosemary E.O. analysis

Compound	% yield
Myrene	4.64
α-Pinene	20.33
α-Terpineol	0.71
β-Pinene	4.87
γ-Terpinene	1.90
Borneol	2.45
Bomyl acetat	1.01
Camphene	9.80
Camphor	15.67
Caryophyllene	2.39
Eucalyptol	23.54
Linalool	0.97
p-Cymene	0.70

Table 5.3 Results of lavender E.O. analysis

Compound	% yield
Octanone-3	0.93
Limonene	2.18
1,8-Cineole (Eucalyptol)	46.49
Cis-β- Ocimene	1.37
Trans-β-Ocimene	0.18
Linalool	1.16
Camphor	9.83
Borneol	12.26
Terpinen-4-ol	0.62
α-Terpineol	0.77
Linalyl acetate	0.19
Lavandulyl acetate	0.30
Caryophyllene	1.37
β-Pinene	5.91

Table 5.4 results of oregano E.O. analysis

Compound	% yield
α-Thujene	0.05
α-Pinene	0.21
Myrcene	0.30
α-Terpinene	1.33
p-Cymene	4.20
γ-Terpinene	3.10
Borneol	1.69
Terpinen-4-ol	16.11
Thymol	0.30
Carvacrol	51.73
Caryophyllene	2.20
Linalool	5.85
α-Terpineol	4.69
Linalyl acetate	4.92

5.4. Valorisation

HYDRO2 utilizes the reclaimed water that is produced from the wastewater treatment in HYDRO1 demo site. A 1 ha agroforestry system with more than 60 plant species is irrigated with this reclaimed water and a variety of products in terms of biomass for animal feed and fresh crops have already been harvested (>10 tons). The aromatic plants harvested together with a variety of fruits and vegetables in HYDRO 2 were given to local restaurants and donated to the inhabitants of the island including deprived families of Antissa village. Besides direct local use of these plants on Lesvos Island, in the future, they can be valorised in the same manner as planned on Mykonos. The extraction of essential oils and production of cosmetics can be branded accordingly with the beautiful HYDROUSA story to be told in addition.

Since the scope of HYDRO2 was not to make an economic profit through sales during these two years, the majority of the produced crops were donated to locals. At the same time, mainly during the second year of operation we were able to test the production of some secondary products. The main products that could be produced from the harvested crops and herbs of HYDRO2 are essential oils and hydrosol water, but also liqueurs, marmalades, dry herbs etc.

The variety of fruits and herbs, the environmental qualities, the applied organic procedures, and the novelty in terms of water used would be able to achieve better prices in the market compared with similar conventional products. In any case, from now on, all the secondary products are produced as trials in order to evaluate the possibilities of producing these valuable products in the future and were given mainly to visitors of the site.

The major derived products that were produced apart from the essential oil are the following (Figures 5.8 and 5.9):

- 50 L of aronia liqueur
- 3 L of different liqueurs from fruits like pomegranate, blackberries, raspberries, strawberries (Figure 5.9)
- 5 kg of aronia marmalade

Figure 5.8. Dried herbs and liqueur produced in HYDRO2

Figure 5.9. Different liqueurs (left) and marmalades and essential oil (right) produced in HYDRO2

6. ANALYSIS

6.1. Challenges

During the implementation of the activities of Task 4.4 several challenges were faced which are summarized to the following:

- The extreme climatic conditions, such as flooding, freezing and severe drought, leading to a reduction of crops had a consequent effect to the KPIs, as HYDRO3 and HYDRO4 presented production losses. This resulted in a reduction in the quantity of the plant biomass available for distillation, but also in a reduction in quality, as the plants distilled in 2022 on Mykonos did not have the opportunity to grow, stabilise and develop during the period of the first two years, as it usually happens in crops planned for commercial production.
- HYDRO6 aromatic plants crop was hit by a fungus, which resulted to a significant loss of several species, but also demonstrated that Lavender and Oregano were the most stable and robust crops.
- Licencing of a professional distiller, even one of small size, (up to 500 L) poses a challenge to anyone who wishes to possess one. It is a time-consuming, lengthy process, which requires determination. It took DEL about 10 months to go through with the whole process and receive the distiller. DEL does not have the possibility to use the unit without the presence of the authorities. Every time a distillation takes place, the authorities must be informed, and DEL must pay a fee of €10 for the unsealing and sealing of the unit. This is of course in line with the current legislation, which has become very strict as authorities try to control the illegal production of distilled alcoholic drinks.
- The co-creation workshop and ethnobotanical study conducted in Lesvos illuminated the importance of agroforestry systems, featuring the cultivation of diverse species and types, as a means to enhance crop diversity for local citizens and establish a replicable business model for the island. Agroforestry, in general, plays a pivotal role in biodiversity conservation through several mechanisms: habitat provision, germplasm preservation, habitat preservation, connectivity establishment, ecosystem services. Thus, it was decided to proceed with the selection of a great variety of crops rather than focusing on the herb cultivation for essential oil production. This strategic shift not only enriches local agriculture, but also establishes a sustainable model for the island's future development. However, it decreased the final total production of herbs within the project.
- As it was stated by experienced distillers, reported in literature and proven by project's results during the first two years of herb cultivations, the yields and quality of plant materials and distillation products are characterized as moderate. Nevertheless, it is anticipated that these factors will experience exponential growth the following years.

6.2. Results analysis

During the last two years of the HYDROUSA project, a series of distillations were performed, giving a total of 11.1 L of pure essential oil and 219.5 L of hydrosol. Thus, the production of around **227 kg distillation product** was achieved that can be sold either as final product or used to produce soaps, creams, etc. In Tables 6.1 and 6.2 the results of the distillation performed in 2022 and 2023 are presented. In those tables a calculation of the yields is given compared to yields available in literature for large scale commercial production of E.O.

Table 6.1 Total biomass & E.O./ Hydrosol production 2022

Crop	HYDRO	Plant biomass (kg)	Essential Oil (ml)	Yield (ml/100g)	Yield% (literature)	Hydrosol (L)
Oregano	2	130.6	295	0.23	0.5-2.3	8
Lavender	2	200	202	0.10	1.0-1.6	22.5
Sage	2	95.5	140	0.15	1-3.5	10
Melissa	2	47	-	-	0.01-0.4	5
Oregano	3	135	980	0.73	0.5-2.3	9
Lavender	4	17.5	180	1.03	1.0-1.6	2
Oregano	6	4.5	40	0.89	0.5-2.3	6
Lavender	6	2	20	1	1.0-1.6	4
Total	all		1857			66.5

Table 6.2 Total biomass & E.O./ Hydrosol production 2023

Crop	HYDRO	Plant biomass (kg)	Essential Oil (ml)	Yield (ml/100g)	Yield% (literature)	Hydrosol (L)
Oregano	2	195	438	0.23	0.5-2.3	14.5
Lavender	2	550	3300	0.6	1.0-1.6	42
Sage	2	151	60	0.04	1-3.5	4
Rosemary	2	250	1100	0.44	0.4-1.5	12
Oregano	3	330	2500	0.76	0.5-2.3	26
Lavender	4	105	1100	1.08	1.0-1.6	11
Oregano*	2	58	286	0.49	0.5-2.3	5.5
Oregano	6	10.5	110	1.05	0.5-2.3	8
Lavender	6	45.3	350	0.77	1.0-1.6	30
Total	all		9244			153

*Oregano produced in HYDRO2 and distilled by DEL during the WICC conference

Based on literature reviews and the knowledge of experienced essential oil producers, that we gathered through interviews and confidential discussions, we realised the pivotal role of the first three years of production in establishing the foundation for a high-quality product. In the initial year, typically marked by meagre harvests, modest yields, and medium-grade essential oils, year two witnesses an upswing with increased harvest, better yield, but still characterized by moderate quality essential oils. By the third year, expectations soar as harvests surge further, yielding significant improvements in both the yield and quality of essential oils and hydrosols, thereby ushering in the first batch of top-tier products.

Conversely, when considering the hydrosols, they are in their second year of harvests, leading to the deduction that distillations in 2022 would have yielded products of moderate quality. It is worth noting an exception, specifically concerning the oregano harvested in HYDRO3 during 2021, which underwent drying and prolonged storage for over a year. This prolonged storage caused a notable reduction in its aromatic constituents. Due to the limited quantity of these oregano plants, they were not individually monitored, observed, or distilled separately in 2023. Instead, the entire crop from HYDRO3 was distilled together.

This practical wisdom, shared among seasoned producers, finds validation in the analytical results obtained from HYDRO3 in 2022, concerning the oregano harvested in the same year and the oregano collected in 2021 (as detailed in section 3.7). Furthermore, a similar pattern is apparent in the results from HYDRO2 in 2023 (detailed in section 5.3).

Table 6.3 Comparison of oregano E.O. constituents between HYDROs and literature values

Constituents	HYDRO3 2021	HYDRO3 2022	HYDRO2 2023	Literature
π-Cymene	27.65	21.28	4.20	0.5-10
γ-Terpinene	15.48	12.88	3.10	0.5-7.00
Thymol	2.35	2.71	0.30	0.3-4
Carvacrol	32.31	41.76	51.73	>65

A good quality oregano E.O. is determined from a high amount of carvacrol. According to literature, it needs to be more than 65%. π-Cymene is a precursor compound of thymol and γ-terpene is a precursor compound of carvacrol thus, at optimum harvest time both should be relatively low, ensuring the highest concentration of thymol and carvacrol in the plant. In the case of HYDRO2 one may see that the two precursor compounds are low, providing a higher percentage of carvacrol. However, as the distillation was performed in the second harvest year it is expected that the E.O. would be of medium quality. At HYDRO3 one sees an increase in the carvacrol levels from harvest year one to harvest year two, but the levels of the precursor compounds are relatively high, which leads to the conclusion that the harvest was performed earlier than it should for providing higher carvacrol and thymol content. As time was pressing at the end of the project and distillations at HYDRO3 were performed within June 2023, it was not possible to have further analysis results for comparison. However, in 2023 DEL has delayed the harvest as much as possible in order to ensure better product quality.

Regarding the yields of oregano distillation in the three different HYDROs, one may see for both 2022 and 2023 that the oregano produced at HYDRO2 distilled on Lesvos provided lower yields than the ones produced at HYDRO3 and HYDRO6, that might be because the harvest was done too early or too late, or because the climatic conditions did not favour the production of carvacrol, e.g. due to increased rains close to the harvest period. At HYDRO3 and HYDRO6 the yields were within the limits set by literature for commercial production of E.O. The oregano harvested in 2023, at HYDRO2 for the distillation demonstration during the WICC conference showed a higher E.O. yield. This is because it was harvested later providing a higher concentration of E.O. In 2023 continuous rainfall during June has led all oregano producers in Greece to a late harvest in mid-end of July. The oregano and lavender at HYDRO2 were harvested during the earlier May-June period, which led to lower yields.

Table 6.4 Major constituents of lavender E.O. 2023 HYDRO2 compared to literature values

Constituents	HYDRO2 2023	Literature
Linalool	1.16	20-50
Camphor	9.83	0-20
1,8-Cineole	46.49	0-39
Linalyl acetate	0.19	1-45

Analysis results were presented for lavender harvested at HYDRO2 and distilled at an external distillery on Lesvos Island. As this is the second year of production it is expected the oil would be of moderate quality. Linalool and linalyl acetate are the major two components of lavender oil and they appear to be very low. 1,8-Cineole (Eucalyptol) is quite higher, and camphor appears to be within the expected limits

of a good quality oil. It is important to state here that lavender is a plant whose constituents vary significantly between species and are greatly affected by the climatic conditions, especially during harvest. Regarding the yields of lavender E.O. produced in all three HYDROs, they were all within the accepted limits for commercial E.O. production.

Rosemary harvested in 2023 (second harvest year) at HYDRO2 was also send for analysis. For rosemary the major constituents and accepted values according to literature are presented in Table 6.5.

Table 6.5 Major constituents of rosemary E.O. at HYDRO2 2023 compared to literature values

Constituents	HYDRO2 2023	Literature
α-Pinene	20.33	9-35
Camphene	9.80	3-10
Camphor	15.67	3-20
1,8-Cineole	23.54	1.5-30
Borneol	2.45	2-15

The results given by the analysis, compared with the values given in literature lead us to the conclusion that the rosemary E.O. produced in 2023 at HYDRO2 is of a good quality and was harvested during the optimal harvest period. According to the above, and the "rule of thumb" stated initially, in 2024 the respective HYDROs should see an impressive improvement in the quality of their distilled products, i.e., E.O. and hydrosols. A trend of increased quantity is already present over the past two years, even after the influence of adverse climatic conditions, like snowfall, floods, pests and fungal infections of the soil and plants.

6.3. Market Analysis

Essential oils and Hydrosols have always presented a prosperous perspective for herb and aromatic plant growers. It is important to note the difference between the sale price of a kg of dried herb and a kg of E.O., in order to mark the financial advantage of distilling aromatic plants.

Table 6.6 Price of Dried Herb / kg

Crop Dried Herbs	Oregano price €/kg	Lavender price €/kg	Sage price €/kg	Melissa price €/kg
Conventional	5-10	13-21	17-21	17-35
Organic / Bio	30-40	20-60	21-30	30-60

Table 6.7 Price of E.O. / kg

Crop Essential oils	Oregano	Lavender	Sage	Melissa
Price /kg €	56 - 400	30 - 300	130 - 220	90 - 300

From the numbers displayed here, it is obvious that there is a quite wide range of prices both for the dried herbs, and for the Essential Oils. Crops and E.O. produced conventionally are cheaper than the ones produced by organic farming processes. Moreover, the range in the price depends on the quantity purchased, i.e., the greater the quantity, the lower the price. In addition to that, the country of origin of

the crop and/or E.O. also plays a significant role, although differences in prices in crops/E.O. produced in the same country have also been detected, a fact that signifies differences in quality of both the dried plant mass and the E.O.

As a means of guaranty, it is often the case that E.O. producers provide analysis results and quality control certificates, proving the exquisite quality of the E.O. and Hydrosols they offer for sale. Additionally, bulk wholesale prices above 1 kg, are in most, if not all cases not available as they are to be discussed and decided upon by both the seller and the client.

The price of E.O. may be up to 10 times more in relation to the price of the dried herb, especially in the case of organic plant distillation. All HYDROUSA demo sites are falling under the category of organic agriculture. As a result, the aromatic plants, the E.O. and Hydrosols produced by all demo sites are also falling in the “organic” category. However, for this statement to be accepted as true, a certification of the HYDROs (2, 3, 4 & 6) would be necessary. Furthermore, the production of cosmetic and self-care formulations with the use of the E.O. and Hydrosols produced at the demo-sites, provide an additional value to the final product.

7. CONCLUSIONS

Task 4.4 "*Production of high added value products*" proved to be a challenging task. However, all partners consider the outcome positive and successful. Obstacles, such as loss of crops, legal restrictions and the restrictions imposed by the pandemic were overcome, the purchase and installation of two distiller units, and the knowledge transfer for cream, lotion, soap and ointment formulation were carried out with success.

After the conclusion of this task, DEL is now capable of distilling the crops produced by HYDRO3&4. Additionally, DEL is in a position and possesses the knowledge and equipment to market the produced essential oils and hydrosols. These can be bottled and forwarded to the market pure in 5ml tinted bottles (for E.O.) and 100 ml tinted bottles (for Hydrosols), or they can be formulated into cosmetics and marketed in this form.

ELT is now capable of organising and leading independently, educational workshops on the topic of distillation by demonstrating the process and formulating cosmetics/care products with the resulting E.O.s and Hydrosols. In addition, the aromatic plants planted on ELTs premisses are being harvested and distilled for conducting these workshops. These products are given to the participants of the workshop and the guests of the Ecolodge.

As it is stated in section 6.2, within the first two years the yields and the quality of plant material and distillation products are moderate. However, both are expected to grow and improve exponentially every year, and with existing knowledge, further income can be generated and inspire other businesses in the region and beyond to apply this type of agriculture combined with the use of non-conventional water sources which in turn yields sustainable and bio-certified products of higher quality and value.

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ANNEX

Figure 8.1. License for constructing, repairing, transporting distilling equipment issued for DEL

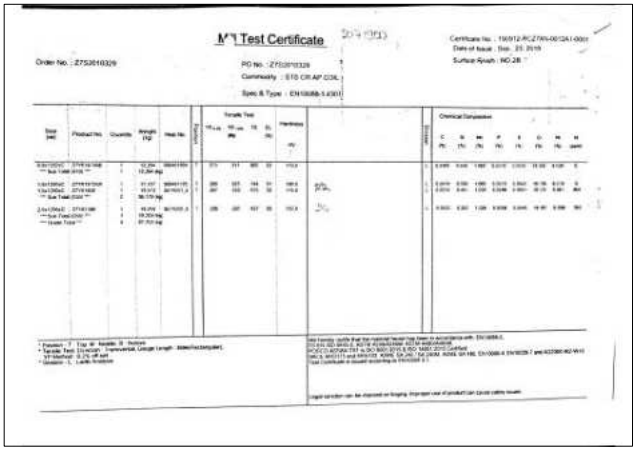

Figure 8.2 Test certificate of the materials

Figure 8.3. The declaration of compliance of the manufacturer

Figure 8.4. The official declaration of material used by the coppersmith

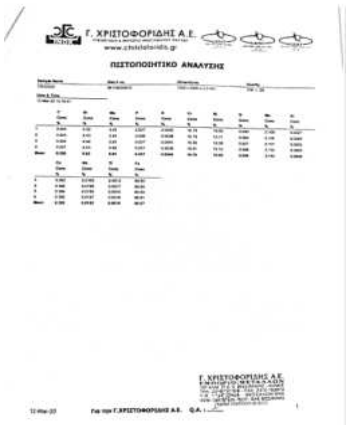

Figure 8.5.Certificate of analysis of the materials used for the distiller

Figure 8.6. License issued for the transport of the distilling equipment

Figure 8.7. The final permit issued for DEL for possessing professional distilling equipment