TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Civil Engineering and Architecture
Environmental Engineering and Management (MSc)

WASTEWATER REUSE IN EUROPE AND VIETNAM

MASTER THESIS

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Supervisor:	Prof. Karin Pachel

Tallinn 2021

(*On the reverse side of title page*)

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Environmental Engineering and Management

THESIS TASK

Student: Minh Hieu Nguyen, 194396EABM
Study programme, main speciality: Environmental Engineering and Management, EABM03
Supervisor(s): Professor Karin Pachel

Thesis topic:
(in English) **Wastewater Reuse in Europe and Vietnam**
(in Estonian) **Heitvee taaskasutus Euroopas ja Vietnamis**

Thesis main objectives:

1. An overview of water scarcity in Europe and Viet Nam
2. Analysis the benefits and drawbacks of wastewater reuse, wastewater reuse trends in Europe,
3. Determination the impacts and present EU legislation and policies for wastewater reuse,
4. Analysis of the best available technology for wastewater treatment for reuse.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Work with scientific literature	15/03/2021
2.	Draft of the thesis	10/05/2021
3.	Final thesis	23/05/2021

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PREFACE

First of all, I would like to express my sincere thanks to Professor Karin Pachel, Head of Environmental Engineering and Management Department at TalTech University, for guiding and imparting valuable knowledge throughout the time of the thesis. I am very thankful to TalTech University for helping and getting me to get a full DORA scholarship in the first year so that I can maintain my tuition and living expenses. I take this opportunity to express gratitude to my teachers in Environmental Engineering and Management Department at TalTech University for having given invaluable knowledge during my university period. I want to thank all my friends at TalTech University for the beautiful moments we shared, for listening, offering me advice, supporting me all the time, and made my college years memorable. Last but not least, I would like to express my deepest love and thanks to my beloved family for always trusting me, for giving me all their inspiration, encouragement, and patience. Thanks for always being there for me, Mom and Dad.

Currently, countries around the world are facing water stress problems due to population growth and climate change. Therefore, the rational use and reuse of water is an important issue towards sustainability. European countries are experiencing indicators of increasing water stress, which requires a reasonable improvement of water use policies. This master's thesis showed details for water reuse in European countries and related aspects. Besides, water reuse in Vietnam is also mentioned and compared. By collecting and analyzing data, the master thesis provides evidence of the Water Exploitation Index, wastewater reuse, advanced water treatment technologies, and regulations of water reuse in European countries. From there, the master thesis provided the related conclusions and recommendations to develop water reuse in a sustainable way.

Keywords: Water Exploitation Index, wastewater reuse, technologies, regulation, master thesis.

List of abbreviations and symbols

Throughout this report, the following abbreviations and symbols are used:

EU	Europe Union
EC	European countries
WEI	Water Exploitation Index
WSI	Water Stress Index
EIPW	European Innovation Partnership on Water
EIP	European Innovation Partnership
EEA	European Environment Agency
WRR	Water Reuse Regulation
UWWTD	Urban Wastewater Treatment Directive
WWTP	Wastewater Treatment Plant
GHG	Greenhouse Gas Emissions
SDGs	Sustainable Development Goals
WHO	World Health Organization
INE	Spanish Statistical Office
COM	European Commission
UWTPs	Urban wastewater treatment plants
CECs	Contaminants of emerging concern
ARB	Antibiotic-resistant bacteria
ARGs	Antibiotic-resistant genes
AOPs	Advanced Oxidation Process
DOC	Dissolved Organic Carbon
PAA	Peracetic acid
JRC	Joint Research Centre
FAO	Food and Agriculture Organization

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1. INTRODUCTION

1.1 General introduction

Nowadays, water scarcity could be a rising problem in many countries, mainly which highly accessed and used in natural water resources [1]. Moreover, in some developed countries, water scarcity raises challenges to developing the economy and the sustainable well-being of people as well as on the whole planet [1]. The problem of water scarcity will be further serious by increasing population, urban development, climate change, or increased demands for food that will continue to expand the distance between water availability and water demand. It may well be seen that water scarcity can be characterized as a lack of adequate water or access to safe and healthy water sources. Water scarcity is expanding, as water is required to grow and process food, generate electricity and serve the increasing population. Climate change may be a significant factor contributing to this shortage.

Moreover, there are various reasons for water scarcity globally, such as increasing human consumption, overuse of water, the shortage of investment in technology and infrastructure to draw water, water pollution, etc. Based on the number of the global water crisis, more than 850 million people do not have fresh water to drink, more than one of every ten people on the planet [2]. Furthermore, agriculture is the largest water-consuming sector globally, accounting for almost 70% of freshwater extraction [1]. Due to increased competition in numerous areas (agriculture, industry) and high economic benefits in urban and industrial applications, treated wastewater is increasingly the most noticeable low in cost and efficient alternative to traditional irrigation water, particularly in the dry and semi-dry regions [1]. In agriculture, wastewater reuse is already widespread in different parts of the world.

In Europe, the over-abstraction of water is a crucial explanation for water stress [3]. The pressure for high-quality freshwater supply and the treated wastewater reused for agricultural activities and urban and environmental purposes has been increasing due to the high water demand and the water stress of the countries. The potential position of the reuse of treated wastewater as an alternative water supply is now recognized and embedded in regional, European and national strategies. According to the EU, the reuse of treated wastewater has both positive and negative impacts. Wastewater reuse can quantitatively boost the environmental status, good nutrient contents for crop production to reduce additional fertilizer use [3]. Besides, wastewater reuse could be seen as a reliable water supply for irrigation, public service, and household activities. On the other hand, wastewater reuse, which is especially untreated or partially handled, may pose various significant risks to general well-being and the environment due to microbial and toxic components. Wastewater treatment aimed at low cost and wastewater reuse for agriculture and industry is the most outstanding issue in major cities for water and environmental services.

In order to minimize the risks of treated wastewater to human well-being and the environment, wastewater treatment requires purifying and disposing of wastewater and removing various hazardous substances [4]. Approximately 70% of global withdrawals of water are currently used to irrigate agricultural land [1]. Estimates show that in the year 2050, the water consumption in agriculture will rise globally by around 20% with existing efficiencies [4]. These issues have created a motivation in finding alternative water supply resources and treatment plants that can help in recirculating nutrients [4]. The reuse of treated wastewater in irrigation is an excellent solution for both problems. Moreover, throughout various research, the reuse of wastewater also brings many economic and environmental benefits such as toilet flushing, power generation, building, car washing, electricity generation, fire-fighting, and farming irritation except for a drinking purpose [5]. Research has shown that in Europe, the reuse of treated wastewater must be addressed in a more global way to be implemented in future regulations. Therefore, it is essential to realize which treatment plant will better safely reuse treated municipal wastewater by the laws and regulations in the current situation [6].

Furthermore, water stress is evolving and continually changing climatic conditions in some European countries, reflected in the extensive use of renewable water supplies, and is a challenge for water management. Water recycling and reuse are viewed to use alternative water supplies and preserve the traditional water resources to better support water resources. Water reuse has become a highly engineered technology in Europe, beginning from a simple recycling process. While there are recognized benefits from water reuse for additional water supply, diminished wastewater discharge, and recycling of nutrients, Europe is still deficient in maximum reused water benefits. Water reuse guidelines are applicable in some Member States and regions for different applications; some general regulations are at the EU level [7]. Apart from excessive withdrawals, there are more droughts and water pressures caused by climate change. How will these problems be tackled? Rising the use of renewable water supplies, including desalinated water and reuse of treated water, and taking action to decrease the need for water is deemed helpful. Water reuse is suggested to alleviate water scarcity. However, there are many reasons why treated wastewater reuse was poorly implemented because of the absence of guidelines, raising concerns such as the risk liability for usage of reused water and the user's aversion to using reclaimed water. In Europe, the reuse of treated wastewater is a significant feature in the European eco-industrial landscape [3]. Unlocking the potential for innovation in water management will contribute significantly to job creation: up to 20,000 new jobs could be created with a one percent rise in the European water industry's growth rate [3]. Therefore, the reuse of treated municipal wastewater has been recognized as a prime concern of the EUROPEAN INNOVATION PARTNERSHIP on water (EIPW) [8]. In several EU countries such as Cyprus, Greece, Italy, Malta, Portugal, and Spain, the reuse of treated wastewater is accepted in practice to deal with water scarcity.

Hence, this thesis will provide an overview of water scarcity in Europe, analyse the benefits and drawbacks of wastewater reuse, wastewater reuse trends in Europe, determine the impacts and present EU legislation and policies for wastewater reuse, and finally analysis and recommend the best available technology for wastewater treatment for reuse.

1.2 Sectoral water use in Europe

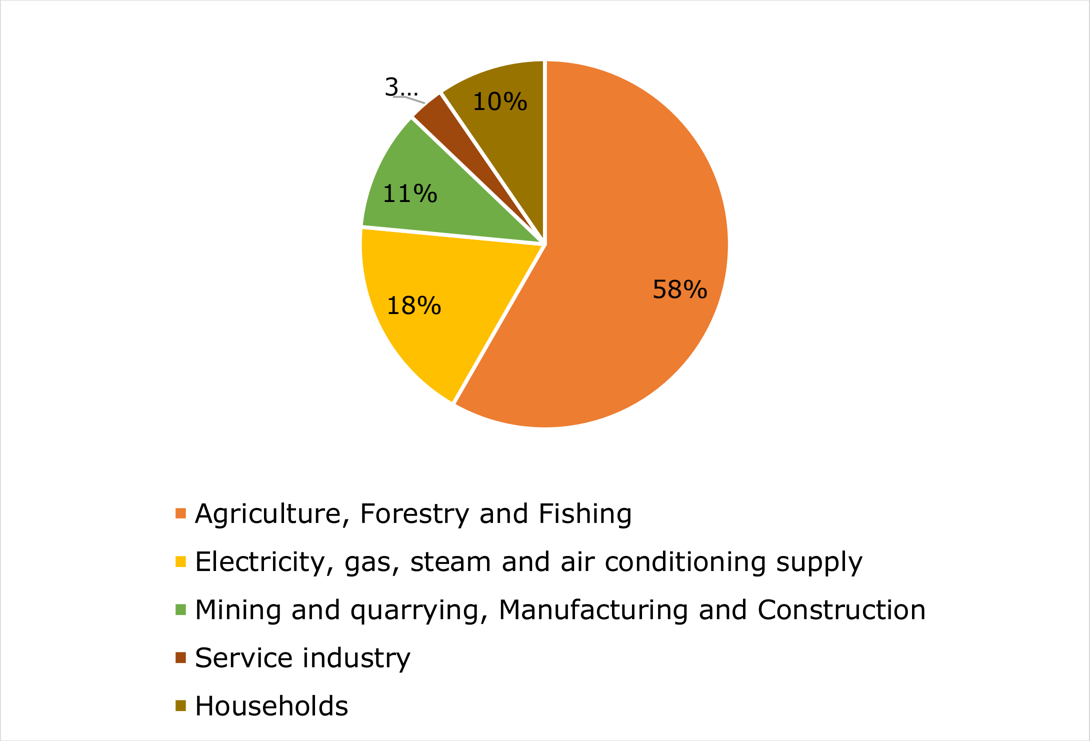


Figure 1.1. Water utilization in different sectors in EU in 2017. Source: www.eea.europa.eu

The highest water use rate belongs to the agriculture sector (Figure 1.1). It could be seen that water plays an essential role in food manufacturing and farming in particular. In the agricultural sector, irrigation is the primary purpose for water use. Irrigation is also used in the production of crops. In general, the high gross value added of vegetables and other plants is also very demanding for water.

Interestingly, the second position after agriculture belonged to electricity production (Figure 1.1) mainly utilized in hydro-electricity. Some countries in Europe mostly use hydro-electricity, such as Austria, Iceland, and Croatia [3]. Besides, other electricity consumers are industries, residences, and entertainment services. These areas may be actively or indirectly pressurizing water supplies. The next and the third position is mining and manufacturing such as fabrics, metal, catering, and paper products with a small portion. Other areas also utilize water in the suitable propose, such as the food processing industry. The percentage of water used in the manufacturing area is a little bit higher than in households (drinking, domestic need, cooking, etc.). On the other hand, water use in the service industry sector such as entertainment, healthcare, etc. is the lowest (Figure 1-1).

Moreover, Europe's water supply is based on natural resources such as rivers or groundwater (Figure 1-2) [3].

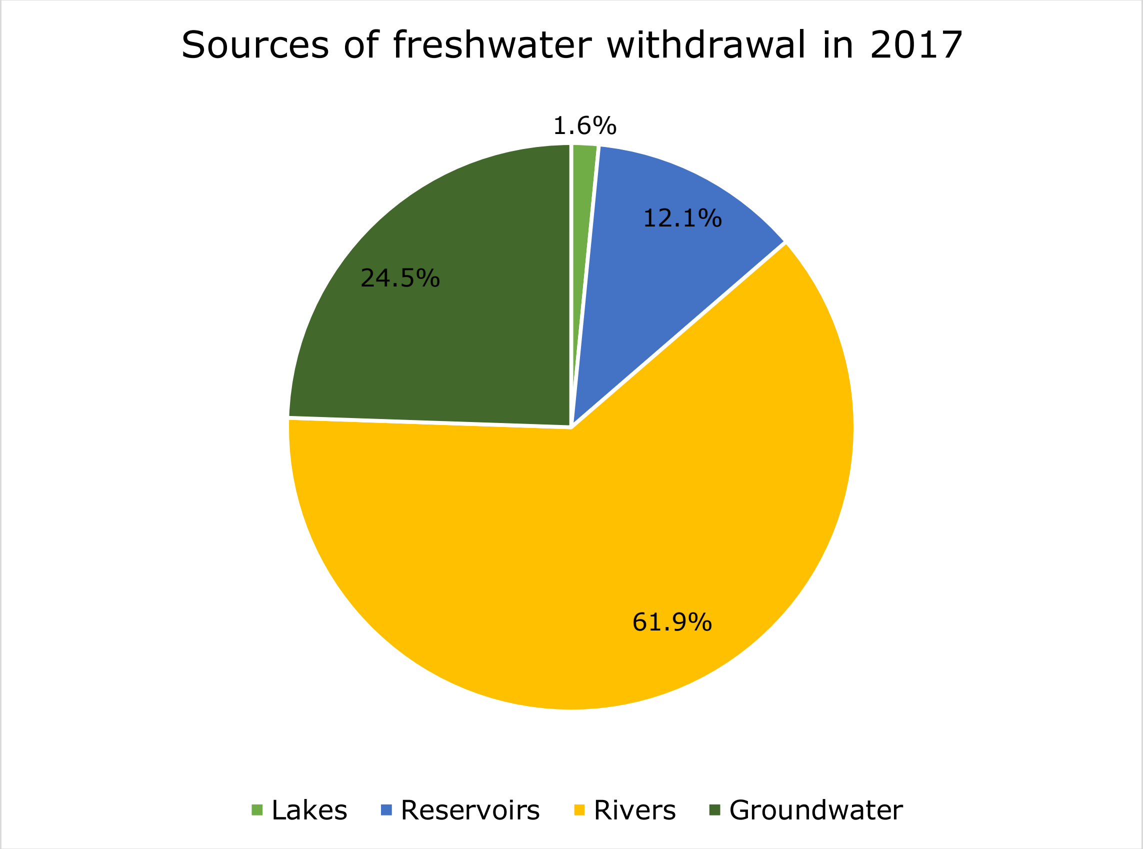


Figure 1.2. Sources of freshwater withdrawal in Europe in 2017. Source: www.eea.europa.eu

Based on the data of the European Environment Agency, rivers water withdrawal dominates about 60% in the European countries. Rivers provide almost the water used for cooling purposes in the energy sector. Groundwater constitute fourth part from the whole withdrawal in Europe. Water abstraction from artificial reservoirs and lakes is about 12% and 2% correspondingly (Figure 1.2).

2. WATER EXPLOITATION INDEX OF EUROPEAN COUNTRIES

2.1. Water scarcity consideration in some European countries

Water will likely become much less common in many places, as climate change tends to lift Europe's average temperature, so finding solutions to preserve the water is significant. Drought and water scarcity are different, but the impact of both can be exacerbated. In some regions, drought severity and duration may contribute to water scarcity, while water sources' over-use can intensify drought effects. Therefore, attention must be paid to the synergies between these two phenomena, particularly in water scarcity impacted river basins.

To begin with, the shortage of freshwater resources to satisfy demand is water scarcity. Water scarcity can be characterized as a lack of adequate water or access to healthy water sources. Water is an urgent need in many parts of the planet. This shortage is spreading as water is required to grow and process food, produce electricity and serve the industry's growing population. Climate change may be a significant factor contributing to this. Water supply issues also occur in low rainfall areas, but often in areas with high population density, intense irrigation, and industrial activity.

Moreover, another water problem that should be considered in Europe is drought [3]. Drought in high and low rainfall areas and any season may occur anywhere in Europe. Drought may be intensified in areas with low water supplies or are not well controlled, leading to imbalances between water demands and the capacity to supply the natural system.

In practice, there are various methods and indicators to observe the water scarcity in Europe, one is the Water Exploitation Index (WEI+). It could be based on the national level or river basins level. In this report, it is based on the national level for most European countries. In the current study, author compared the WEI+ of European countries with Vietnam, an Asian country with high population-based river basin levels. This report's limitation is the lack of a reliable database for most Asian countries to compare.

2.2. Water Exploitation Index

2.2.1. Water Exploitation Index of European countries

The water exploitation index (WEI) defines the water scarcity in the ratio between the volume of renewable freshwater availability resources per capita and total water withdrawals per capita. The water exploitation index (WEI+) of European countries (EC) is based on the national level. The water exploitation index proportion should be lower than 10% if the value range of WEI from 10% to 20% shows that the renewable freshwater availability could be a limit or a constraint in this country's eco-social development and need to be invested in supplying for sufficient water demand. It is defined as moderate water stress. For the WEI that higher than 20%, the community or government needs to put more effort into managing and balancing the water supply and demand of the over-population or urbanization problem. If the value reaches or more than 40%, the country will face an extreme water stress situation, and the utilization of the country's freshwater is inefficient. In brief, it could be said that:

- < 10 %: low stress
- 10 % - 20 %: low-to-medium stress
- 20 % - 40 %: medium-to-high stress
- > 40 %: high stress

In this study, thirty-five European countries are taken into consideration and calculated based on EUROSTAT data as a combined chart below [9].

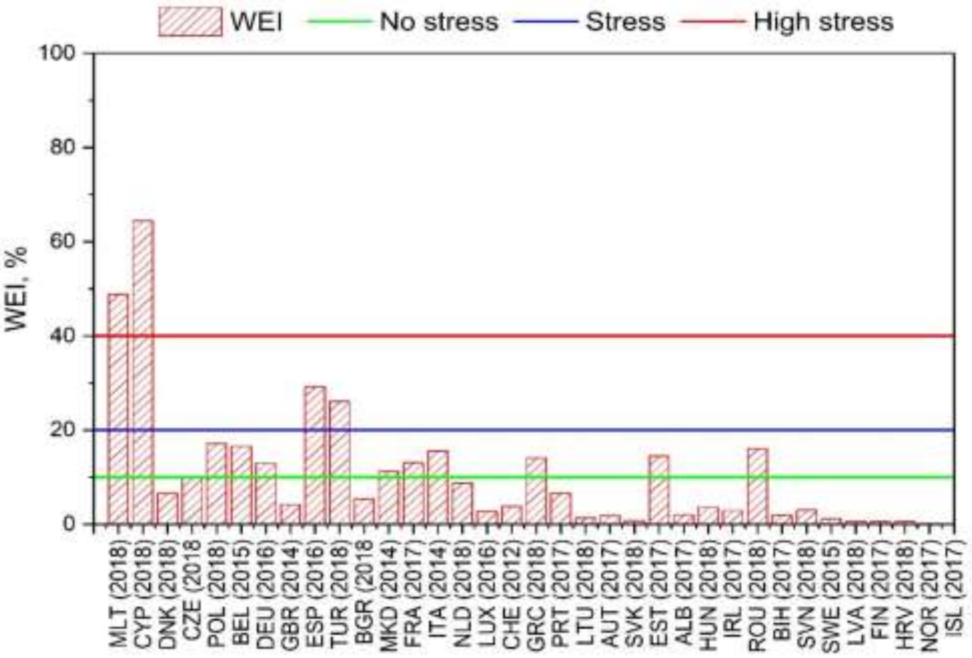


Figure 2.1. Water Exploitation Index (WEI+) of European countries. Sources: Eurostat

What is worth mentioning about the situation is that water stress is high in Cyprus, Malta and medium-high in Spain, Turkey (Figure 2.1). Belgium, Germany, Estonia, France, Poland, Romania are classified as moderately water-stressed (low-to-medium). The rest of the countries, like Bulgaria, Denmark, Croatia, Latvia, Lithuania, Luxembourg, Netherlands, Portugal, Finland, Sweden, etc., are considered as low water stress. However, the Water Exploitation Index (WEI+) still has some limitations, such as it does not take into account artificial increases in the water supply (using the desalinated method). Moreover, it does not recognize countries' capacity to adapt by evolving actions or new technologies to less water availability. The Water Exploitation Index (WEI+) fails to consider water availability seasonally and ignores the reuse or recycle of wastewater and withdrawal water. Analysis of the data shows that for some countries, for example Belgium and Estonia. WEI is rather high due to non-consumptive water - water that is abstracted and used but returned directly back to the source without significant changes and delay. In Estonia, such water is cooling water for power stations that constitutes about 70% of the whole water abstraction.

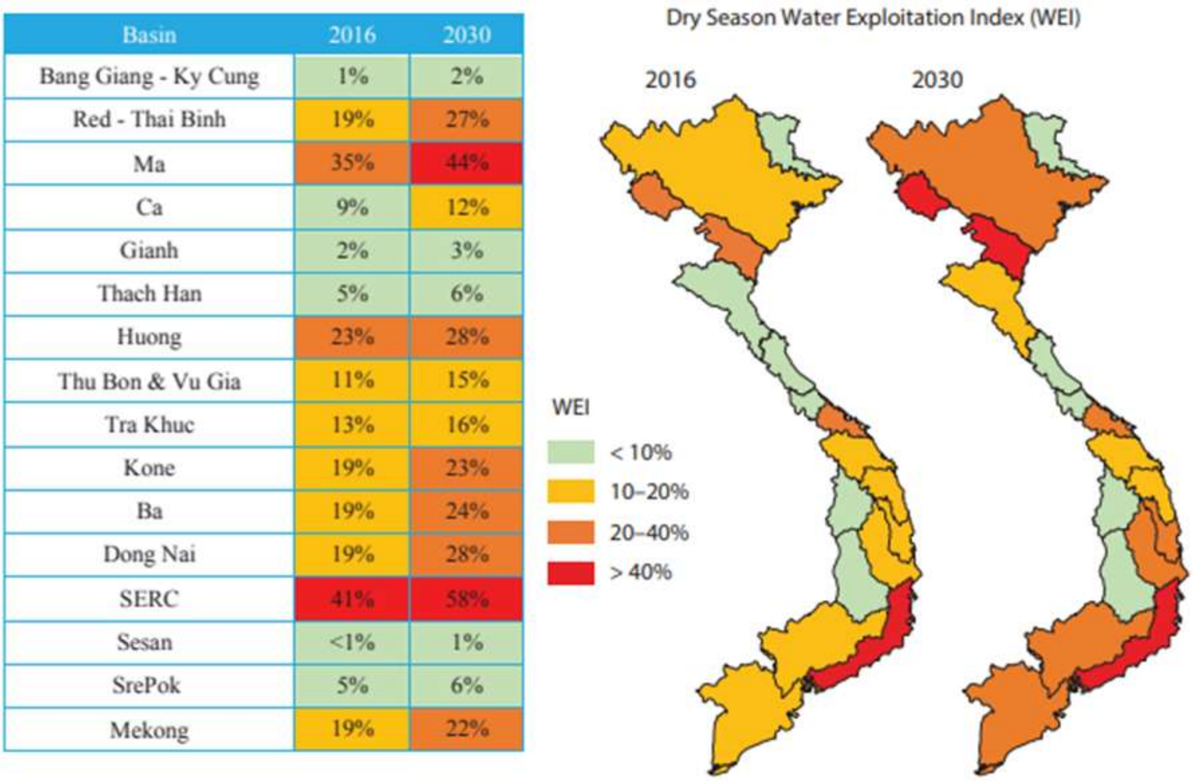
2.2.2. Water Exploitation Index of Viet Nam

Vietnam is a long, thin S-shaped country located in the continent of ASIA. Vietnam has a small surface area, covers an area of more than 331,000 km^2, and this is the 65th largest country in the world by region. There are five cities with more than one million inhabitants, including Ho Chi Minh, Ha Noi, Hai Phong, Can Tho, and Da Nang [10]. Ho Chi Minh is the biggest city with more than eight million inhabitants. Moreover, the current total population in Vietnam is estimated at 96,462,106 people in 2019, with the Gross Domestic Product (GDP) was worth 261.921 billion US dollars in 2019 [11].

Nowadays, with the high human population, Vietnam is facing one of the biggest problems of keeping pace with escalating environmental pollution with rapid urbanizations, especially in the larger cities. Rapid population growth, urbanization, and the freshwater crisis have escalated the need for wastewater reclamation for Vietnam. Despite the widespread reuse of wastewater, its importance has not achieved adequate attention from Vietnamese people. Because of a low-income country, Vietnam is unlikely to provide numerous adequate and modern wastewater treatment infrastructures. Another reason for the need for wastewater reclamation is the excess groundwater exploitation for domestic and industrial use. Moreover, discharge of untreated wastewater, freshwater exploitation for domestic, agriculture, and industrial activities from the upstream of Sai Gon and Dong Nai rivers, have affected the depletion of surface water quality.

Figure 2.2. Map of Viet Nam waterbodies (rivers and lakes)

Actually, in Vietnam, water is also mainly utilized in agricultural irrigation. The provinces and cities of Vietnam where rivers are attached are mainly agricultural areas (Figure 2.2). Moreover, one of Vietnam's most significant environmental concerns is water pollution [12]. Nearly 80 percent of Vietnam's illnesses are affected by water pollution [12]. Therefore, the reuse of treated wastewater could be a desirable option in Vietnam. In Viet Nam, there are two seasons, including the rainy season and dry season. Based on the report, a chart illustrated the Water Exploitation Index (WEI+) based on river basin flows (Figure 2.3). It spreads across Vietnam in the year 2016 and an estimated or forecasted scenario in the year 2030 [13].



Basin	2016	2030
Bang Giang - Ky Cung	1%	2%
Red - Thai Binh	19%	27%
Ma	35%	44%
Ca	9%	12%
Gianh	2%	3%
Thach Han	5%	6%
Huong	23%	28%
Thu Bon & Vu Gia	11%	15%
Tra Khuc	13%	16%
Kone	19%	23%
Ba	19%	24%
Dong Nai	19%	28%
SERC	41%	58%
Sesan	<1%	1%
SrePok	5%	6%
Mekong	19%	22%

Figure 2.3. Water Exploitation Index of Vietnam in 2016 and estimated in 2030, Source: World Bank, 2019

What is worth mentioning about is that the differences in the water exploitation index of the North and Mekong Delta of Viet Nam. In the North, the colour has changed from yellow to orange, which means that River Red -Thai Binh will have high water demand and extraction in 2030. Moreover, Ma River will become severe water stress, and the use of Ma River’s water will be unsustainable in 2030. For the Mekong Delta River, the water stress will be changed into a medium-to-high stress level. Therefore, the government should manage and control water exploitation properly to prevent the water stress or scarcity situation in some major rivers in the dry season across Viet Nam like a forecasted scenario in 2030.

Due to the rapid increment of the population and high water demand for domestic, industrial, and agricultural purposes in Viet Nam could be resulted in the forecasted scenario in the year 2030 without proper water management method and an alternative water source. The dry season in Viet Nam will start from November to April/early May During the dry season, water scarcity occurs near river basins when the river water source gradually runs out. If compared with the forecast for Europe in 2030, it can be seen that the scarcity of fresh water in Vietnam is severe, the use or extraction of water is unsustainable. In Vietnam, rainwater or upstream reservoirs could be seen as an alternative option in the rainy season. Still, it also has many drawbacks because it is only sufficient and dependent on the rainy season of Viet Nam. Moreover, being dependent on the rainwater will require high investment to build large areas for collecting and storage for rainwater. Besides, rainwater could not be seen as a reliable water supply resource.

2.3. Water Stress Index

This part will introduce the calculation of WSI in the European countries

2.3.1. Water Stress Index of European countries

Falkenmark indicator is among the most frequently used method to estimate the water stress, this method is focused on a per person water supply measurement each year in a nation or area [14]. If the result of WSI is higher than 1700 m^3 per capita, it means that the country has no stress in the water scarcity problem. For the range 1000-1700 m3 per capita, the country faces with the problem in the scarcity, from 500 to 1000 m3 per capita is the scarcity's value range and below 500 means absolutely scarcity. With the total renewable water resources achieved from AQUASTAT database [15] and the number of population from DATA WORLD BANK [11] in the year 2017,
A formula is used to calculate the Water Stress Index (WSI):

$$\textbf{WATER STRESS INDEX (WSI)} = \frac{\text{Total renewable water resources}}{\text{Population}} \; \textbf{(}\mathbf{m^3}\textbf{ per capita)}$$

Therefore, this report applies the population-water equation to calculate the WSI number of European countries in year 2017 (Table 2.1 and Figures 2.4)

Table 2.1. Water Stress Index of European countries in 2017. Source: AQUASTAT

	COUNTRIES	**Total renewable water resources (10^9 m^3/year) in 2017**	**Population**	**WSI, m^3 per capita**
1	Malta (MLT)	0.0505	467999	108
ABSOLUTE SCARCITY (< 500 m^3 per capita)				
2	Cyprus (CYP)	0.78	1179680	661
SCARCITY (500 - 1000 m^3 per capita)				
3	Denmark (DNK)	6	5764980	1041
4	Czech (CZE)	13.15	10594438	1241
5	Poland (POL)	60.5	37974826	1593
6	Belgium (BEL)	18.3	11375158	1609
STREES (1000 - 1700 m^3 per capita)				
7	Germany (DEU)	154	82657002	1863
8	United Kingdom (GBR)	147	66058859	2225
9	Spain (ESP)	111.5	46593236	2393
10	Turkey (TUR)	211.6	81101892	2609
11	Bulgaria (BGR)	21.3	7075947	3010

12	North Macedonia (MKD)	6.4	2081996	3074
13	France (FRA)	211	66864379	3156
14	Italy (ITA)	191.3	60536709	3160
15	Netherlands (NLD)	91	17131296	5312
16	Luxembourg (LUX)	3.5	596336	5869
17	Switzerland (CHE)	53.5	8451840	6330
18	Greece (GRC)	68.4	10754679	6360
19	Portugal (PRT)	77.4	10300300	7514
20	Lithuania (LTU)	24.5	2828403	8662
21	Austria (AUT)	77.7	8797566	8832
22	Slovakia (SVK)	50.1	5439232	9211
23	Estonia (EST)	12.81	1317384	9724
24	Albania (ALB)	30.2	2873457	10510
25	Hungary (HUN)	104	9787966	10625
26	Ireland (IRL)	52	4807388	10817
27	Romania (ROU)	212	19587290	10823
28	Bosnia and Herzegovina (BIH)	37.5	3351527	11189
29	Slovenia (SVN)	31.87	2066388	15423
30	Sweden (SWE)	174	10057698	17300
31	Latvia (LVA)	34.94	1942248	17989
32	Finland (FIN)	110	5508214	19970
33	Croatia (HRV)	105.5	4124531	25579
34	Norway (NOR)	393	5276968	74475
35	Iceland (ISL)	170	343400	495050
NO STRESS (> 1700 m^3 per capita)				

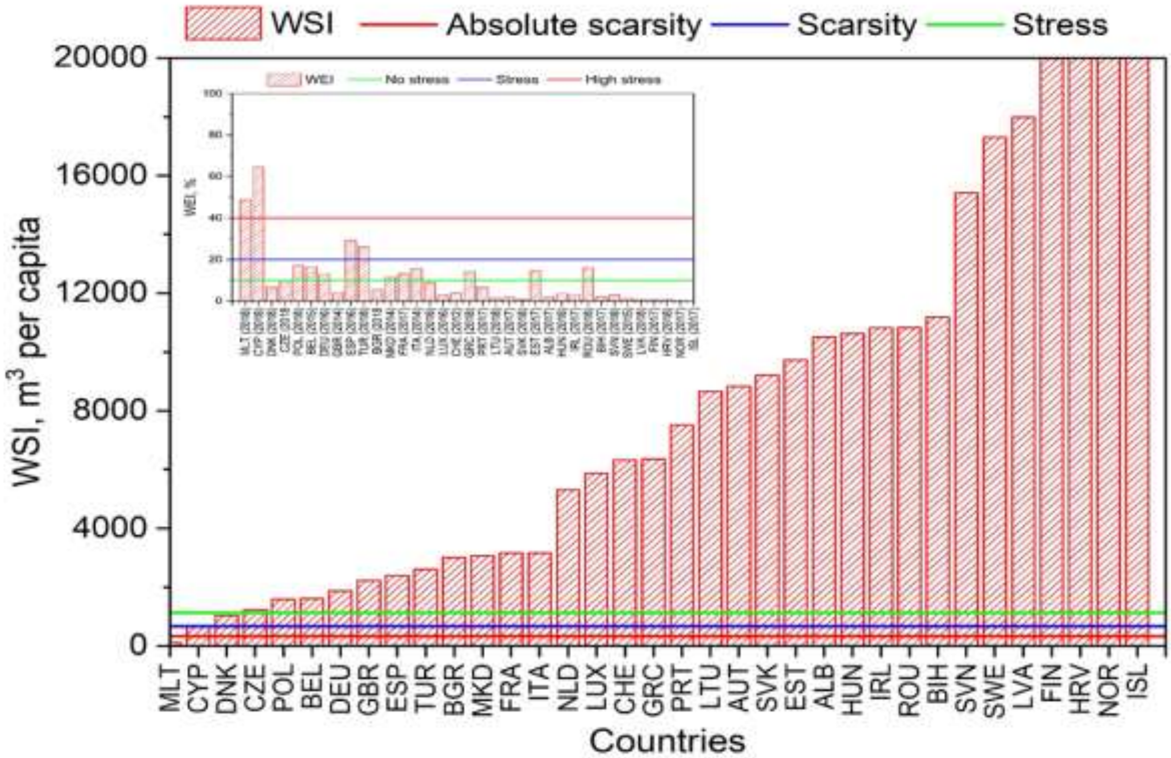


Figure 2.4. Water Stress Index of European countries in 2017

What is worth mentioning about the table above is that in 2017 there is only one country in Europe with the water stress index is lower than 500 m^3 per capita is Malta, it means that the water resources are absolutely scarcity. Moreover, there was one country with the value in the average range of 500 – 1000 m^3 per capita is Cyprus, Cyprus has been facing with the water scarcity. There are four European countries in the range of 1000 – 1700 m^3 per capita such as Denmark, Czech, Poland, Belgium, the total water renewable resources per capita per year is quite stress. The rest of European countries, such as Germany, Spain, Italy, Estonia, Romania, Netherlands, Hungary and other are with the values higher than 1700 m^3 per capita. It means that those countries did not face with the problem of water stress in the year of 2017 but it will not last if the country does not know how to exploit or use the water properly. However, the WSI is only the indicator based on the country level to measure and evaluate the water stress level of that country, it also ignores the regional differences in the water availability. In addition, the WSI is not responsible for the accessibility of water resources, for example, a country can store deep underground or heavily polluted some of its freshwater resources. Furthermore, the Water Stress Index (WSI) is just the function of number, it is not actually the volume of water that a person uses each year.

When looking at the data on WEI and WSI, Malta is a European country with high water scarcity levels. With a relatively large population, Malta has the lowest per capita water use of any country, resulting in an absolute scarcity level. Similarly, Cyprus is the country with the highest water scarcity index; their water use per capita is also very low. Therefore, these countries need to have appropriate water recycling and water reuse policies. Spain and Turkey are also countries with high water scarcity levels, but they do not experience water stress problems. This is due to their water regeneration policies and rational use of water. Other countries also experience mild stress on water scarcity, such as Poland, Belgium, Germany, Romania, etc., but almost no water stress proves reasonable water regeneration. Countries like Finland, Croatia, Norway, etc., have practically no water stressors with their abundant water availability.

2.3.2. Water Stress Index of Vietnam

In this part, this report also applies the Water Stress Index (WSI) method mentioned above to calculate for Viet Nam in the year 2017 as table 2.2 below:

Table 2.2. Water Stress Index of Vietnam in 2017. Source: AQUASTAT database

VIET NAM	
Population of Vietnam in 2017 [16]:	94596642
Total renewable water resources in 2017 (10^9 m^3 per year) [17]:	884.1
WATER STRESS INDEX (WSI) (m^3 per capita):	9346
NO STRESS (> 1700 m3 per capita)	

Hence, the threshold in Vietnam in 2017 was 9346 m^3 per capita (water available for one person). It was over 1700 m^3 per capita but it just assumes that water resource pressure is the function of the number only, not actually the amount of water that each person actually uses. This function also ignores the differences of the water availability in different regions or cities, only measures the water scarcity level of a typical country because some of the water resources could be heavily polluted and not be able to supply. This water scarcity threshold even does not consider seasonal differences of water availability. Moreover, it does not take into account changes in water supply by human beings (such as desalination).

Based on the chart of Water Exploitation Index (WEI) and table of Water Stress Index (WSI) of some European countries, it could be seen that some countries have been facing with the problem of water stress or scarcity because of high water demand. Fresh water in Europe is under growing stress, and the demands for and availability of water supplies on both temporary and geographical scales are disturbingly different. Water saving is a major concern, especially for domestic use, due to the energy consumption associated with the delivery, usage and treatment of water. The frequency and severity of droughts and their environmental and economic disruption seem to have been increased [18]. The Joint Research Centre (JRC) impact report investigated the effects of climate change on water changes in Europe [18]. In 30 years, climate change has affected global warming, global temperatures have risen to 3 °C. Countries in Europe are also hard impact by the global warming. In which, according to JRC, Southern European countries are the place most affected by the climate change; The JRC has warned that these countries will face increasing water stress, especially Malta, Cyprus, Portugal, Spain, Greece, Turkey, and Italy. Meanwhile, climate change is leading to polar ice melting. Therefore, Central and Northern European countries have an increasing annual water supply due to this influence. This causes a growing disparity in water tension among the European regional nations. Therefore, the wider reuse of treated wastewater for agricultural, industrial and urban activities could in particular improve Europe's capacity to respond to risks of water shortages and droughts. In a number of European Member States, reuse of water is recognized as an integral and efficient part of water resource management, subject to water scarcity (for instance Cyprus, Spain, Italy) [19]. In such circumstances, the reuse of water may have a smaller effect on the environment than other alternative water sources such as water transfer or desalination. However, the proportion of treated wastewater reuse in European countries is small but the reuse of treated wastewater could be considered as an alternative water supply for different sectors and as a significantly potential improvement to combat with the water scarcity or shortage. The reuse of wastewater is really important and potential in EU with various environmental and economic benefits. Therefore, before reusing water, wastewater needs to be considered carefully what kind of wastewater should be reused, which sectors to be used and its potential for reuse as well as possible human being health risks. In addition, it is also important to thoroughly understand the policies to encourage and support the reuse of wastewater and find out which technology is best available for wastewater reuse. Therefore, this report will explore and analyse those factors for wastewater reuse in the following section.

3. WASTEWATER REUSE IN EU

3.1. Types of reused water

Based on the Water Reuse Regulation (WRR), published on May 2020 in the ninth regulation, defines that the reuse of well-treated wastewater from urban wastewater treatment plant, for example, is known to have lower environment effects than any other water alternative methods of water supply (including water desalination and transfer) [20]. Based on the Urban Waste Water Treatment Directive (UWWTD), the treated municipal wastewater could be reused if water is passed as minimum the secondary treatment [21]. Domestic wastewater does not contain industrial effluents, which can endanger the operation of the wastewater system, treatment plant, environment or human health. The sixteenth regulation of Water Reuse Regulation (WRR) also say that for the human health risk assessment, the reuse of treated wastewater could not be used for the drinking purpose [20]. Reclaimed water is generally described as wastewater treated for removing organic matter, solids, and certain forms of impurities. The treated wastewater has a certain quality, which is compatible with the intended uses, typically at a lower level than the quality of drinking water. Based on the report, in the primary treatment, suspended solids would be removed from the municipal wastewater, BOD5 will be diminished at minimum 20 percent prior to disposal, the total suspended solids would be minimized exactly a half [22]. Primary treatment’s purpose is the reduction in suspended solid, BOD5, floating materials, etc. Moving to the secondary treatment plant, in general, requires biological processes eliminate the organic matter and the residual suspended solids [22]. In most cases, additional treatment is needed in order to reduce the health and environmental risks involved in the re-using of treated wastewater and change the water quality to the intended use. This further stage, known as 'tertiary treatment' consists mainly removing pathogens, nitrogen, dissolved solid (salt) and chemical pollutants [22]. When treated wastewater is used directly for drinking water production, further treatment with advanced filtration methods is appropriate, but in this report does not consider for the application of drinking water purpose [22]. In view of the advanced technological level in the treatment of wastewater and the variety of technologies, it should be noted that secondary treated wastewater might have a bacteriological quality comparable to surface freshwater. This report also involved the reuse of treated industrial wastewater for external applications because internal recycling is considered as a range of national and EU policies have already been supported. Moreover, this study does not consider the reuse of rainwater, the type of wastewater to be reused in this report would be urban and industrial wastewater.

3.2. The applications of treated wastewater reuse

The direct reuse of treated industrial or urban wastewater could be applied in different sectors such as [23]:

- Agricultural applications: irrigation water, food processing, milking animal pastures, greenhouse, fodder
- Industrial applications: cooling, processing and washing aggregate water, construction industry (concrete production and dust control)
- Urban applications: public park irrigation water, car washing, toilet flushing, dust suppression, fire fighting
- Recreational applications: irrigation of the golf course, hotels, parks
- Environmental applications: recharge of aquifers (to increase water in quantity and quality for saline intrusion control and delayed abstraction), wildlife habitat, water for the preservation and regeneration of current or new marine habitats
- Increasing the availability of water for later drinking water development

All the applications mentioned above are the direct use. There is another use, called or known as indirect use. The treated wastewater would then be transferred in the natural body of water such as river, lake, aquifer and some of them will be subsequently recuperated for future usage.

3.3. Environmental and economic benefit

This chapter is based on studies of the Amec Foster Wheeler Environment & Infrastructure [8, 24]. The reuse of treated wastewater has environmental, economic and social advantages, as well as possible disadvantages. In order to ensure well-being and environmental protection, the risks of treated wastewater reuse must be dealt with and solved. This chapter will provide many environmental, economic benefits and drawbacks of the reuse of treated wastewater.

3.3.1. Environmental benefits

- First of all, the reuse of treated wastewater will improve the natural and man-made flow of rivers and pools, thus helping to accomplish surface water systems quantitative targets.
- At that time, the reuse of treated wastewater to recharge aquifers will achieve robust growth and prevent the deterioration of groundwater. However, it is necessary to ensure that the quality of the treated wastewater does not negatively affect the above mentioned water sources.
- Moreover, in some areas of EU countries with the situation of water scarcity, the treated wastewater reuse could be seen as a stable water supply and increase the water availability. In other EU countries with the situation of water stress like Cyprus, Malta, Denmark or Poland, the reuse of treated wastewater could have a lower impact to the environment than other alternative like desalination [8].
- There are some Wastewater Treatment Plants (WWTP) that discharge their treated water into the ocean, which results in the waste of a water supply resource. Treated wastewater reuse means the recycling of this water to increase resistance to shifts in water demand and climate change.
- When using less energy to properly handle wastewater disposal relative to water import, draining deep land waters, desalination of seawater or exporting wastewater, the water source is being used and the energy needs for water delivery will lead to decreased greenhouse gas emissions (GHG) [24].
- The reuse of treated wastewater can help to minimize the use of artificial fertilizers thanks to irrigation nutrients contained in the treated wastewater.

Therefore, planned treated wastewater reuse is still better than unplanned treated wastewater.

3.3.2. Economic benefits

In the EU-level instruments for water reuse, treated wastewater reuse is considered as a water supply resource and has a number of economic advantages [8].

- A more reasonable benefit of wastewater reuse to economy is that wastewater reuse will help achieve a relevant water price and create incentives to lower the demand for water and cost-saving.
- Using treated wastewater in agricultural irrigation will improve more productive and effective farming.
- As mentioned above, treated wastewater could be used in industrial sector that help save the cost and enhance competition and innovative stimulus. Treated wastewater could be used in many processes such as cooling, boiler feed, etc.

- In some countries such as Spain, Italy, Malta Cyprus, treated wastewater reuse will indirectly support for the tourism industry with the development of some activities such as irrigation for golf courses, hotels and park irrigation.
- By giving an alternative irrigated water supply for farming, reclaimed water will enhance the food security.
- To help achieve the Sustainable Development Goals (SDGs) by improved water supply and sanitation, environmental conservation, through the use of suitable technical solutions (goal number 6) [25].

However, the general view of treated wastewater reuse can be unfavourable in some countries and water reuse policies can be distrusted.

3.4. Environmental, human health and economic risks

3.4.1. Environmental and human health risks

This chapter is based on studies [8, 22], the environmental and human health risks are included as follows:

- Raw wastewater comprises a broad variety of contaminants and species that pose a possible health and environmental danger. For example, pathogens like bacteria, parasites, viruses may cause diseases. Secondary treatment could decrease these pathogens considerably, but further treatment is usually required to ensure clean water for reutilization. There are some pollutants regulated under EU legislation [8].
- Water quality conflicts are also experienced through run-of treated wastewater into surface or ground water [8].
- According to WHO, where water is not handled properly until reuse, pathogens and compounds can be harmful both to the environment and human health through farming irrigation, direct contact with water, or unwashed/not cooked vegetables intake in which the pathogens exist. Pathogens contaminated on these plants cannot be cleaned efficiently even by the use of chlorinated water [8]. Substances can maintain and build up over time in soils or groundwater to deteriorate the climate.
- It is very necessary to consider and recognize the environmental and human health risks to find out a suitable type of required treatment and management of wastewater. It is also important to realize that further treatment is needed or not
- Other important factors such as collected water quality, water table's depth, vadose zone in aquifer recharge (zone of high microbial activity) and surface

runoff need to be considered to monitor the risks and quality of treated wastewater [8].

- The reuse of treated wastewater may be useful for the avoidance of secondary environmental effluent leaks to the environment.
- Where the wastewater is disinfected with chlorine, the reuse of treated wastewater will cause the release of residues from the treatment that may destroy marine systems [8].
- In the risk evaluation of soil quality, the impacts of the use of treated wastewater and other items such as chemical fertilizers and pesticides should also be considered [20].
- Both water quality and quantity requirements are linked to ecosystems, environments, plants and habitats [22]. Wastewater reuse preparation must ensure that ecosystems and environments are preserved.

3.4.2. Economic risks

- Based on the final report of EU's instrument on water reuse, the reuse of treated wastewater is more costly than the conventional resources include costs for treatment, management and infrastructure [8].
- The reuse of treated wastewater is not only an expensive option when compared with the abstraction of conventional resources but also with low investment returns [8].
- A variety of schemes has gained advantages from direct or indirect subsidies to promote the demand and supply of treated wastewater reuse. This situation must need further consideration, especially in term of recovery cost and financial sustainability in water management sector. Moreover, the conventional resource's price should be either subsidized or retained low for irrigation sector [8].
- The reuse of treated wastewater also requires infrastructure costs such as treatment plants, systems for water distribution (building water transport pipelines), irrigation systems, could entail funding and the economic feasibility [8].
- The general view on the reuse of treated wastewater among EU Member States can be either negative or conflicting, leading to a loss of interest in water reuse activities [8].

3.5. Overall situation of water reuse in the EU

After analysing the water scarcity and water stress index of the European countries, this chapter will mainly look for data and analyse the overall situation of treated wastewater reuse in many European countries.

3.5.1. Current situation

From the analysis of WEI and WSI in the previous chapter, it can be seen that in Europe there is no a widespread water shortage or scarcity, but major gaps occur between some European countries in the volume of water reuse per year, in term of water conservation and water risk management. Moreover, increases in water demand, competitions from various sectors such as agriculture, industry, with long-term worries about the consequences of global warming on water resources and availability, further emphasis the efficiency of reused water. Various countries in the northern Europe such as Latvia, Lithuania, Finland, Denmark, Sweden don't have to face with the problem of water stress and have adequate water supplies so additional treated wastewater reuse is currently not seen as a high priority. A lot of countries in the southern Europe or Mediterranean region such as Cyprus, Bulgaria, Croatia, Malta, Slovenia, additional water supply from treated wastewater can offer and provide numerous advantages for farming (irrigation), tourism sector (such as golf irrigation, hotels, parks). Some European countries with water shortage or scarcity occurring often such as Cyprus and Malta have established water reuse as a crucial part of their sustainable water supply management strategy [26].

During the time looking for data, this report found that currently statistics on volume of water reuse of European countries are not complete and updated; the latest update was in year 2018 in EUROSTAT database. In EUROSTAT database, there are only the reported data on volume of treated wastewater reuse for direct use, volume of reused water per inhabitant and volume of reused water for manufacturing industry. There are no reported data on the volume of reused water for public water supply or for agriculture. In EUROSTAT statistics, the volume of reused water is the water going through wastewater treatment and provided for direct use. Therefore, internal recycling water industrial facilities, indirect use to water body such as lake, groundwater aquifer recharge is not included. The table 3.5.1-1 below describes the volume of reused wastewater per year from 2009 to 2018 in the unit of million cubic meters (106 cubic meters per year).

Table 3.1. Volume of reused water per year from 2009 to 2018 (Mm^3). Source: EUROSTAT

COUNTRY/YEAR	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Bulgaria	5.9	6.2	6.4	8.4	8.0	1.7	1.4	1.7	7.8	7.8
Spain	534.0	491.0	608.0	548.0	531.0	530.0	511.0	492.0	-	-
Croatia	180.9	178.8	178.9	176.6	176.3	174.5	168.9	173.6	173.3	172.6
Cyprus	19.7	22.5	25.2	27.1	27.6	26.9	-	29.2	-	-
Malta	1.3	1.3	1.3	1.2	1.1	1.1	1.0	1.1	0.6	0.7
Slovenia	-	-	-	-	-	21.3	22.1	20.8	22.2	25.5
Sweden	-	69.0	-	-	-	-	69.0	-	-	-
Turkey	-	-	-	-	-	-	-	33.1	-	52.1
- : no data provided from EUROSTAT										

Based on the table above, there are only eight countries presented data on the volume of reused water from 2009 to 2018. Numerous countries have not provided the data on the volume of reused water. From 2013 to 2016, an enormous decrease occurred in Bulgaria on the volume of reused water from 8 Mm^3 to 1.7 Mm^3 and after that the volume has been increased noticeably. With 492 Mm^3 per year, Spain was a country with the highest volume of reused water in 2016 compared to other countries. In Estonia, the data were only presented from the year of 2000 to 2009. However, the reuse of treated wastewater has been recognized and applied in various European countries with water scarcity problems such as Malta, Italy, Spain or Cyprus.

Next, this report also takes the estimation of the current volumes of reused water from national scales or articles into consideration:

- In Spain, recently, the amount of reused water reported by Spanish Statistical Office (INE) was 493 Mm^3 per year, approximately to 500 Mm^3 per year in 2016 [23]. Based on AQUASTAT database [15], in 2017, the volume of treated municipal wastewater for direct use was 592 Mm^3 per year. Moreover, Spain was ranked as the leading country in the volume of treated wastewater reuse by the EU and ranked as the world's top ten in 2018 [27]. The vast majority of this water is used for agriculture. Water reuse is an accepted practice, as Spain is subject to water scarcity.
- In Portugal, a new legislation was published in 2019 to support the reuse of treated water in non-potable uses (agricultural irrigation, street cleaning, toilet flushing, irrigation for golf course, etc.) or even for ecosystem [28]. The projects must require the approval from the Portuguese Ministry of the Environment and the quality standards of reused water are chosen in accordance with ISO standards to minimize the environmental and human

health risks. Based on the AQUASTAT database, in 2017, the volume of treated municipal wastewater for direct use was almost 3 Mm^3 per year [15].

- In Malta, many projects have been invested in the technology for water reclamation for reuse for different purposes because Malta is one of the EU countries that suffer from water stress all year round. In the Maltese Islands, there are three Waste Water Treatment Plants that are currently being operated. The reclaimed water produced at the Waste Water Treatment Plants is being utilized for the irrigation in agriculture. A distribution network specifically to distribute polished water to fields has been set up throughout the island. Besides that, a number of distribution points are also available for farmers to get water through a sprinkler. A system of prepaid cards was set up to control the water distribution. In this country, groundwater is also less likely to be overexploited. So even during droughts when other irrigation sources may not be available, farmers will still benefit from a safe supply of water. Hence, this will ultimately lead to an overall improvement in Malta's water stress problems.
- In Cyprus, water stress also occurs in this country. Therefore, the essential water source is reused treated wastewater. Government policy has specific provisions on this issue. The treated wastewater in wastewater treatment plants is reused for agricultural irrigation. When the need for irrigation is limited only during the winter period, a small amount of tertiary wastewater is discharged into the sea. According to 2016 data, 51.4% of treated wastewater is directly reused for irrigation for treated wastewater from wastewater treatment plants, and 16.1% is in aquifers at Ezousa and Akrotirifor irrigation purposes, 27.6% of the treated water flow into the Serrachis River in the dry season, and the remaining 1.5% is stored in the Polemidia Dam for irrigation. Only a small amount during winter when the need for irrigation is limited is discharged to Athalassa Reservoir and the sea [19].
- In the UK, treated wastewater is used to maintain the flow of rivers. This is common in large rivers and provides a substantial amount of water for the public water supply. The water in these rivers is mainly used to irrigate golf courses, gardens, parks, carwashing, fish farming, cooling, and industry. Total water demand in the UK is more than 40% for household use. Of which, 30% of water reuse is used to flush the toilet. At the moment, the UK has just planned or directed emerging reuse sectors and the UK government has not yet introduced legislation on the reuse of wastewater [19].
- In Italy, nowadays, reusing treated water is also an important priority. Of which, about 60% of the treated water is used in agriculture; about 25% of the

treated water is utilized in the industrial and energy sectors, and about 15% of the treated water is used in the civil sector [19].

In 2017, the amount of treated urban wastewater reuse is also given in different countries in Europe as a table 3.2 below.

Table 3.2. Volume of treated urban wastewater for direct use in 2017. Source: AQUASTAT database

Countries	**Volume of reused water (Mm^3 per year)**
Belgium	3
Germany	42
Greece	104
Spain	592
France	411
Italy	45
Cyprus	15.4
Latvia	12
Lithuania	5
Malta	0.6
Netherlands	8
Poland	3
Portugal	3
United Kingdom	164

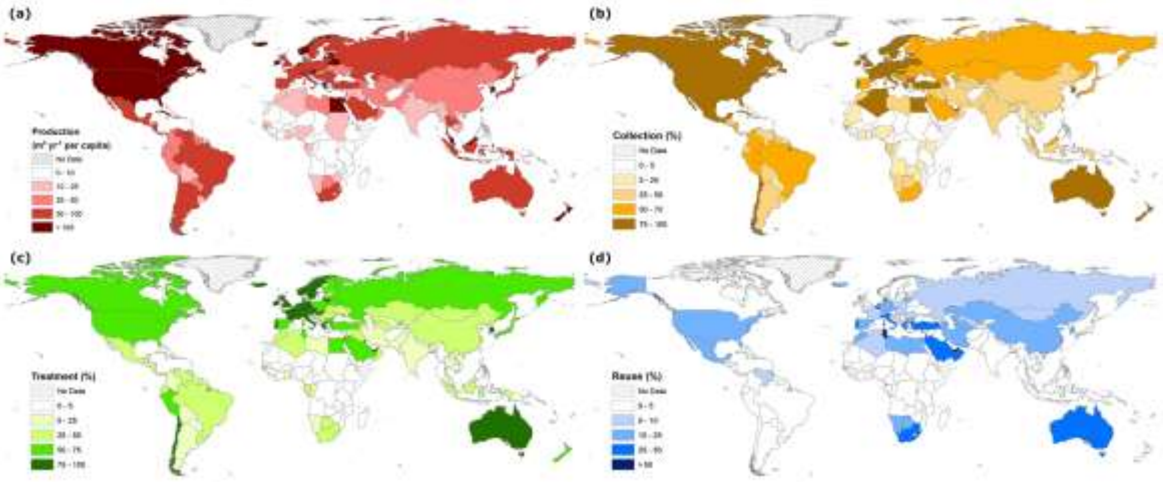


Figure 3. 1. Wastewater production (a), collection (b), treatment (c) and reuse (d) at global [29].

Research by Jones et al. shows that the amount of globally produced wastewater collected and treated is about 63% and 52% respectively; of which about 84% of collected wastewater is being treated [29]. Globally, reuse of wastewater accounts for about 11% of total wastewater produced. The author's research results also show that about 22% of the treated wastewater is reused purposefully; The remaining 78% is discharged into the environment. In the production, collection, treatment, and reuse of wastewater among countries, significant differences occur between different geographic regions and by economic development level. Notably, in North America, the data show that this is the region with the highest wastewater production per capita; more than double that of Western Europe, the next highest wastewater production per capita region. By contrast, most African countries located in the sub-Saharan region produce less than 10 cubic meters per year per capita. In terms of volumetric flow rates, East Asia and the Pacific regions produce the most wastewater, coinciding with the largest proportion of the population (about 31%). By contrast, although accounting for 24% of the population, South Asia generates only about 7% of global wastewater. While about 20% of global wastewater production in the North American region has only about 5% of the world's population. Besides, the research also shows that production wastewater between countries around the world also changes depending on the difference in economic development level. The close relationship between wealth and wastewater production regardless of geographic location has been shown to be closely related. Countries with a high level of economic development have much higher wastewater production than other countries. In terms of wastewater collection and treatment rates, Western European countries have the highest rates; in which, the rates of wastewater collection and treatment are 88% and 86%, respectively. Meanwhile, South Asia and the African countries near the Saharadesert have the lowest rates of wastewater collection and treatment. In South Asia, the ratios were 31% and 16%, respectively, while the Africa region near the Sahara was 23% and 16%, respectively. Despite being home to high total production wastewater, wastewater collection rates are very low in East Asia and the Pacific. On the other hand, the rate of wastewater collection in North Africa and the Middle East is relatively high at 74%; This is likely due to water stress in these areas and a lack of renewable water supplies. Notably, in South Asia, the Caribbean and Latin America, the rate of wastewater treatment is essentially lower than the rate of wastewater collection, likely to show rates of reuse of untreated wastewater. The rate of wastewater collection and treatment follows patterns similar to that of wastewater production for income levels. High-income countries collect and treat most wastewater to low-income countries for a billion small collection and handling rates.

The reuse of treated wastewater occurs mainly in the North Africa and Middle East, with Qatar, Kuwait, and the United Arab Emirates reusing more than 80 percent of their wastewater produced. Developed countries on small islands where water is scarce, including the Malta the US Virgin Islands, and the Cayman Islands also had high rates of reusing treated wastewater at 67%, 75%, and 78%, respectively. The reuse of treated wastewater is very low in areas with low wastewater treatment rates, such as sub-Saharan Africa and South Asia. The highest rates of wastewater reuse are in Western Europe, the Middle East, and the North Africa by region. Through the information collected above, Europe is also the region in the world with relatively high wastewater collection, treatment, and reuse rates.

4. WASTEWATER REUSE IN VIETNAM

Reusing untreated wastewater in aquaculture and agriculture is a popular and widespread practice in rural Vietnam. The urban developers and several industries have begun to reuse treated wastewater toward landscaping and cleaning purposes. However, wastewater reuse has not been widely applied in Vietnam, but there are notable opportunities in the areas with the water stress. Nevertheless, some sludge and wastewater contain substantial volumes of nutrients that may be utilized in the irrigation and agriculture. Sludge resource recovery has not been the centre of wastewater plans so far. Therefore, resource recovery from wastewater has considerable potential in Vietnam. Vietnam's wastewater collection, treatment, and reuse efficiency are relatively low in the region. According to the statistics in 2018, Vietnam has 28 large cities with high population density with centralized wastewater treatment systems. Average water consumption in urban Vietnam varies significantly, ranging from 33 to 213 litres / day per capita. It is estimated that the average water consumption is 101 litres / day per capita in the average urban areas. In highly urbanized areas, this consumption reaches 130 litres / day per capita. About 90% of urban households with septic tanks receive domestic wastewater, in most cases only from the toilet. Grey wastewater from kitchens and drainage is mainly discharged directly to the sewer. The septic tank's accumulated sludge, the septic tank, or the manure sludge is periodically pumped out for treatment and destruction. However, only 4% of the baffles were satisfactorily treated and treated. In urban areas, about 70-80% of urban households had entrance to a piped sewage system (seen in Figure 4.1). The remaining 20-30% of wastewater was released through a soaking pit into a nearby canal or river. About 60% of the urban population in Vietnam is connected to wastewater treatment facilities by connecting to wastewater collection systems and sewerage systems [13]. But, only 4% of domestic wastewater and 17% of urban wastewater in Vietnam are safely treated through a central treatment plant.

There are 45 centralized wastewater treatment plants in operation, with a total capacity of 960,000 m^3/day. Currently, the Government plans to build 50 more wastewater treatment plants, with a full capacity of about 2,200,000 m^3/day [13]. With a low collection and treatment rate coupled with a leak of septic tanks, water pollution is widespread. Urban wastewater is the most significant cause of water pollution. Cities such as Ho Chi Minh City and Hanoi discharge ecosystems of approximately 700,000–900,000 cubic meters of wastewater per day. The wastewater treatment technologies used vary widely among municipal wastewater treatment plants. Most of the wastewater treatment plants in Vietnam use relatively old technologies. Therefore, the treated wastewater is of low quality, so it is not recovered and reused but discharged back to canals and rivers.

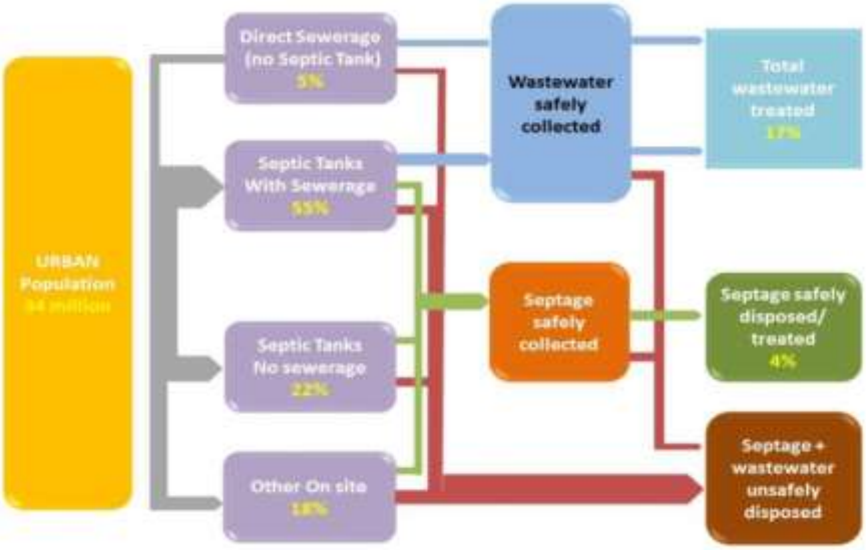


Figure 4.1. Urban wastewater management in Vietnam [13]

It is the consequence of a long history of neglect in wastewater systems and cities' sewerage. Due to the popularity of combined sewers (carrying both rainwater and wastewater), domestic wastewater accounts for 30% of the discharge to rivers, canals, and lakes. The Government of Vietnam has issued Decree 38/2015 / ND-CP of waste management that encourages reduced water use and increased reuse of treated wastewater. However, the Government still does not yet have clear guidance to implement this Decree in any areas of wastewater reuse. One of the traditional activities in Vietnam is to reuse wastewater in agriculture. Farmers pump water from canals and rivers to irrigate their rice fields, vegetables, and fish ponds. With this approach, farmers can save money by using nutrient-rich wastewater and avoiding or reducing the purchase of fertilizers and fish pellets. However, this is really dangerous as untreated wastewater can pollute the irrigation of vegetables and fish farming.

In another study, the authors estimated that 658,000 farmers used wastewater to irrigate 43,778 ha of land in Hanoi [30]. While some tasks in Thanh Tri district have identified widespread use of wastewater for aquaculture (185 ha fishponds) and agriculture (25 ha), producing 3,000 tons of fish and generating 5,760 USD/ha per year and 7,200 USD/ha per year, respectively, from vegetables and fish [31]. Most of this reuse by Vietnamese farmers is without a concrete and informal plan; reused water sources are polluted and inadequate. National standards on the quality of reused wastewater for irrigation (QCVN 39: 2011/BTNMT) do not seem to be of much interest in aquaculture and agriculture. There are very few examples of established urban/industrial wastewater reuse. In particular, with a typical example, a developed urban area in Ho Chi Minh City has pioneered the reuse of wastewater for landscape purposes in the process of high-quality urban development [32]. In Ho Chi Minh City, Phu My Hung is a high-quality urban development. The system of separate sewerage is connected with more than 90% of households transporting wastewater to two wastewater treatment plants, Canh Doi and Nam Vien. Canh Doi wastewater treatment plant with a capacity of 10,000 m^3/day and Nam Vien wastewater treatment plant 15,000 m^3/day treated wastewater collected from 2007 and 2009, respectively. The treated wastewater was reused to irrigate landscapes and green spaces. Meanwhile, sludge after recovery was reused to fertilize trees. The cost of total investment for the two wastewater treatment plants is 5.8 million USD. The water treatment meets Class B discharge standards, and resource improvement offers a good living environment in the Phu My Hung [32]. It was estimated one of the essential standard new urban areas in Vietnam. A recent study shows that reusing treated urban wastewater can reduce Ho Chi Minh City's water stress to low-stress levels by 2030. Water reuse potential Output for non-potable water use is up to 3.7 million m^3/day. The additional investment required to meet the Class B standards is estimated at 0.25 USD/m^3. To continue to reuse treated wastewater in agriculture and aquaculture, it is important to raise awareness about the importance of safe wastewater reuse for all stakeholders. In addition, detailed technical guidance and appropriate standards should be developed and adopted to accelerate the application of reuse practices.

According to the Prime Minister's Decision No. 432/QD-TTG, the need for the development of standards for reusing domestic wastewater in Vietnamese conditions has been raised. Decree No. 54/2015/ND-CP also provides incentives for economic and efficient water use. To encourage reuse activities, the State has implemented incentives for economical and efficient use of water. Environmental issues are always concerned and considered by the Government as one of the essential goals of promoting national sustainable development. The Government of Vietnam has determined that wastewater, if not properly treated or used for the wrong purposes, will pollute the environment and directly affect human health. The rapid development of urban areas and the effects of climate change are increasing the water demand. Besides, the scarcity of clean water for domestic use and agricultural production creates new challenges for Vietnam. Reusing wastewater in agriculture is seen as an essential goal of Vietnam. Agricultural production is the most important production sector for the development of Vietnam. Agricultural production is also the industry that uses the most water.

However, Vietnam still does not have a regulation and guideline standard for using reused water in urban and agricultural areas. Currently, the existing wastewater quality control standards in Vietnam include QCVN 14:2008/BTNMT regulates the maximum permissible value of pollution parameters in domestic wastewater when discharged into the environment [33]; QCVN 40:2011/BTNMT stipulates the maximum permissible value of pollution parameters in industrial wastewater when being discharged into receiving water sources [34]; QCVN 08:2015/BTMT regulates surface water quality parameters [35]. These regulations only provide a general way; there is hardly any specific regulation for reusing wastewater in urban and agricultural areas. Therefore, the Government of Vietnam should consult standards on water reuse in other countries around the world; from there, make the regulations in accordance with the conditions in Vietnam. The main scientific basis of the development of the quality of reused water is based on the comparison and comparison with the standards of developing countries in combination with the existing wastewater quality standards in Vietnam, such as QCVN 14: 2008/BTNMT; QCVN40:2011/BTNMT, and QCVN 08:2015 BTNMT.

5. APPLICATION OF ADVANCED TECHNOLOGIES FOR WASTEWATER TREATMENT IN EUROPE

5.1. Advanced wastewater treatment technologies

According to Rizzo et al., Conventional municipal wastewater treatment plants (UWTPs) are relatively low efficiency at removing disturbing contaminants (CECs), bacteria, and antibiotic-resistant bacteria. These pollutants lead to many concerns for the environment and human health, mostly if the UWTPs is reused to irrigate crops. Recently, because the European Commission is currently developing a regulation on water reuse, interest among stakeholders has increased in Europe. Conventional wastewater treatment plants will likely be required additional advanced treatment steps to meet water quality limits for wastewater reuse. This topic presents advanced technologies based on the studies of Rizzo et al [36]. Advanced technologies include ozonation, activated carbon adsorption, chemical disinfectants, UV radiation, advanced oxidation process (AOPs), and membrane filtration.

- Ozonation: one of the most advanced and efficient water treatment processes is the ozonation process. This process was primarily used to treat and sterilize drinking water. The essence of this process is due to the oxidation that creates free radicals •HO and molecular ozone, which are powerful oxidizing agents that can oxidize the pollutants present in the wastewater and kill bacteria. Recently this process has been studied extensively for wastewater treatment. The effectiveness of ozonation has been demonstrated by the authors' studies [37, 38]. In particular, this process has been shown to effectively remove organic pollutants from municipal wastewater such as sulfamethoxazole, diclofenac, carbamazepine, bezafibrate, and benzotriazole. However, this process has the disadvantage of easy to create byproducts after the process. These byproducts can pose even more significant hazards than that of the pollutants. Therefore, there should be auxiliary processes in place to limit the unwanted byproducts of this process. Besides, for the bacteria present in wastewater, their treatment efficiency for ozonation is also effective within a certain range [39]. However, there are also few studies that demonstrate the effectiveness of this process for its bactericidal properties. Among European countries, Switzerland is a leading country in the application of ozonation in wastewater treatment. However, this process also needs auxiliary processes to maximize efficiency of the process.
- The adsorption of activated carbon: another process that is also highly effective in wastewater treatment is the adsorption process using activated carbon. Unlike ozonation, this process produces almost no by-products after the treatment time. Thanks to its excellent porosity, activated carbon can absorb almost completely the

pollutant compounds in wastewater in a short time. These processes have also been extensively studied for urban wastewater treatment [40, 41]. However, the most significant limitation to this process when applying large-scale wastewater treatment is the high operating costs. Therefore, this process cannot be met when using urban wastewater treatment in large cities. In addition, the competitive adsorption process is also a major disadvantage of this process. The competitive adsorption process can reduce the overall treatment efficiency, so it needs detailed supervision. For the sterilization and sterilization processes, the adsorption process is hardly designed to be this applicable. Therefore, this process has almost no bactericidal effect. European countries such as Germany and Switzerland are leading countries applying this technology in wastewater treatment plants [42]. Therefore, it is also possible to use this model to other models to improve wastewater treatment plants' general treatment efficiency.

- Chemical oxidizing agents/disinfectants

+ Chlorination: this process is also an effective method for municipal wastewater treatment. The most commonly used chlorination agents are chlorine gas and hypochlorite. This process effectively treats CEC in wastewater such as roxithromycin, trimethoprim, cephalexin, ampicillin, etc... [43, 44]. Studies have shown that this process is less effective than oxidation and advanced oxidation. And just like ozonation, chlorination also produces toxic byproducts. However, this process is highly effective in disinfecting and sterilizing wastewater. Chlorination is effective against resistant bacteria and bacteria in sewage. Therefore, it can be seen that this process should not be prioritized for CEC treatment but rather over disinfection and sterilization. Therefore, this process can be used as an auxiliary part of a wastewater treatment plant to improve efficiency.

+ Disinfection by peracetic acid (PAA): PAA is a powerful disinfectant with high redox capacity and a strong bactericidal effect against bacteria. This process is highly effective in treating CEC as it is a strong oxidizing agent [45, 46]. Its effectiveness is also rated lower than that of advanced oxidation and ozonation process. However, like chlorination, this process also produces toxic byproducts, so it requires strict management and monitoring. As with chlorination, disinfection with peracetic acid is highly bactericidal. Therefore, this process is more concerned by the researchers about its sterilization and bactericidal ability than CEC treatment.

- UV radiation: This is an effective technology in disinfection and sterilization [47, 48]. This technology has also been widely applied to disinfect and reuse urban wastewater. The efficiency of the process depends on the intensity and duration of UV irradiation. However, for actual wastewater, turbidity and suspended solids present in wastewater will limit this method's use. These factors will reduce the exposure of UV rays to pollutants and bacteria in the wastewater. On the other hand, this process has been virtually ineffective for CEC treatment because UV rays are almost ineffective against CEC. Therefore, it is necessary to apply this model in line with other models in order to improve the general treatment efficiency of wastewater treatment plants.

- Advanced oxidation: one of the most advanced technologies currently applied in urban wastewater treatment is the advanced oxidation process. The effectiveness of this process largely depends on the generation of reactive free radicals [49-51]. These free radicals have strong oxidizing potential such as superoxide radical ($O2^{\bullet -}$), hydroperoxyl radical ($HOO^{\bullet}$), hydroxyl radical ($\bullet OH$), and alkoxyl radicals ($RO^{\bullet}$), capable of completely oxidizing the CECs into CO_2 and H_2O. This is considered to be the most effective oxidation process and is being studied and widely applied. In the two homogeneous (UV/H_2O_2, $UV/Fe/H_2O_2$, O_3, O_3/H_2O_2, etc.) and heterogeneous (solid semiconductor + light source, UV/TiO_2, UV/ZnO) groups, now the homogeneous group dominates and is commonly used in advanced wastewater treatment plants in the world [52]. The advantage of this process is that the contaminants can be treated quickly and completely oxidized in a short time. Whereas heterogeneous process results in less efficiency as well as more complex reaction system, the cost of running the process is higher. Besides CEC oxidation, advanced oxidation also brings about certain efficacy in bactericidal due to the formation of free radicals. Therefore, this process has excellent applications and occupies an important place in advanced wastewater treatment plants.
- Membrane filtration: This is also an effective method in urban wastewater treatment. This process has long been used in the treatment of drinking water. However, nowadays, with the development of wastewater treatment processes in factories with advanced technology, this process has come to application in wastewater treatment for reuse [59]. Membrane separation processes include ultrafiltration, nanofiltration, microfiltration, and reverse osmosis. With the nanofiltration structure, contaminants and bacteria can be effectively removed. In particular, the nanofiltration and reverse osmosis processes effectively remove organic and inorganic CECs [53]. Meanwhile, microfiltration or ultrafiltration processes are commonly used as ultrafiltration or reverse osmosis pretreatment to control membrane fouling and solids removal and disinfection. For nanostructured membranes, most of the processes can treat water with a very high degree of purity. However, this process has the disadvantage that the separated waste stream contains many pollutants and harmful bacteria. This needs to be handled by another support process.

Table 5.1 provides a comparison between the processes and their effectiveness under personal assessment of this study. Obviously, each method of use has its own advantages and disadvantages. Some processes are effective for CEC treatment in wastewater, while some are effective for disinfection and sterilization.

Table 5.1. Advantages and disadvantages of advanced water treatment technologies under personal assessment of this study

Wastewater technologies	**Advantages**	**Disadvantages**
Ozonation	- CEC can be treated at a basic level. - Highly effective for disinfecting and disinfecting water.	- Easy to create toxic byproducts after CEC treatment.
Absorption of activated carbon	- High CEC treatment efficiency. - Short time for CEC processing. - Does not form harmful byproducts.	- Competitive adsorption occurs, reducing the efficiency of the process. - High operating costs. - Almost no antibacterial and antiseptic effect.
Chemical oxidizing agents / disinfectants	- Highly effective in disinfecting and sterilizing.	- CEC treatment efficiency is lower than other methods. - Easy to create toxic byproducts after CEC treatment.
UV radiation	- Highly effective in disinfecting and sterilizing. - Does not form harmful products.	- Ineffective in the removing CEC. - Requires water without the solids or the suspended organic matter.
Advanced oxidation process	- Provides high CEC treatment efficiency, even at low concentrations. - Diversity in treatment solutions, depending on the requirements of the wastewater treatment plant. - High bactericidal efficiency.	- Easy to create toxic byproducts after CEC treatment.
Membrane	- Effective for CEC removal.	- High operating costs.

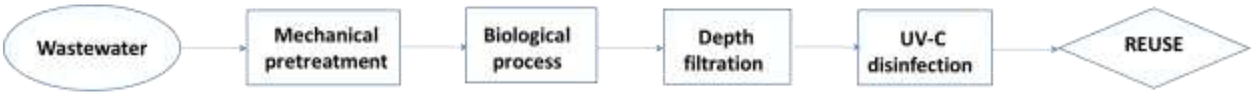
	- Bacteria can also be eliminated. - Does not form harmful byproducts.	- Wastewater stream after the deep filtration process should be treated.

Besides, some technologies work for both but either result in toxic byproducts or too high operating costs. Therefore, in order to overcome the disadvantages of each process, improve overall efficiency and reduce operating costs, it is required to incorporate these advanced processes in the wastewater treatment plant. Combining the techniques will improve the advantages of sending each process, and at the same time, overcome their disadvantages. The methods that combine different advanced processes simultaneously with traditional processes will be presented in the next section.

5.2. Combination model of advanced wastewater treatment plant methods

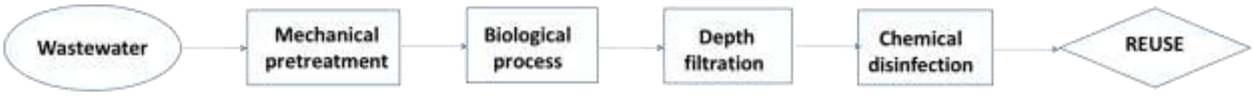
This topic would like to propose four advanced wastewater treatment models from the studies of Rizzo et al [36]:

- Model 1:



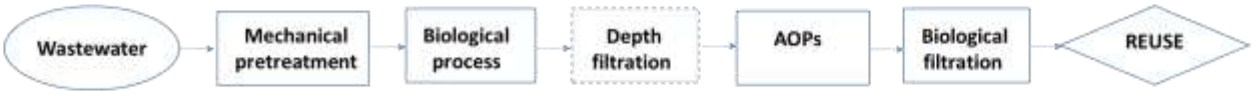
Wastewater collected into wastewater plants will first go through mechanical treatment to remove water-insoluble solid compounds. With these mechanical methods, mechanical impurities and suspended matter of large size and weight will be separated from wastewater. Next, the wastewater undergoes a biological treatment process based on microorganisms, mainly saprophytic heterotrophic bacteria present in the wastewater. Microorganisms present in wastewater use organic compounds as a source of nutrients and energy. Products of these decomposition processes are CO_2, H_2O, N_2, sulphite ions, etc. Based on this process, a large number of organic compounds in water will be decomposed. Next, the deep filtration model will be used; since a large number of organic compounds in the wastewater have been removed, it leaves almost only inorganic compounds, and a small amount remaining this process will be effective when used. At the same time, the shortcomings of this process have also been overcome because a large amount of organic matter in wastewater has been decomposed. The final step of the process is to use UV-C energy to perform disinfection before reusing the wastewater. Thereby, the reused wastewater has been treated almost entirely with CECs and sterilized and disinfected.

- Model 2:



Another model has the same effect. The disinfection and sterilization process will be replaced by chemical disinfection. The disadvantages of chemical reduction, such as the creation of toxic byproducts, have been overcome because when wastewater is treated to this process, CEC is almost completely treated.

- Model 3:



For this model, after biological treatment, deep filtration can be used or not. If used, it reduces the burden on the advanced oxidation process and the biological filtration at a later stage. The AOPs process is used in the back to enable both CEC and bactericidal treatment by the formation of free radicals during the reaction. Because to differentiate the formation of byproducts after the reaction, the biological filtration is designed right behind. This is a process that can deeply treat and treat CECs and resistant bacteria almost thoroughly. The quality of reused water reaches a very high level.

- Model 4:

This is one of the advanced models with high efficiency in wastewater treatment. The adsorption process will be used after the biological treatment to reduce the cost of this process. The inorganic compounds, heavy metals and remaining organic compounds will be processed through adsorption. To overcome the disadvantages of the desorption process in the adsorption process, the deep filtration process is designed right behind. Meanwhile, the sterilization process can be done by ozonation or through UV-C irradiation. Wastewater through this process can reach a high purity, can meet most of the European effluent standards.

6. LEGISLATION SUPPORT FOR WASTEWATER IN EUROPE

6.1. European regulations

In the Member States where water reuse is in place, standards have been set by Greece, Cyprus, Portugal, France, Italy, Malta, and Spain. These standards are legally binding for all countries except Portugal. Many standards developed at the Member State level have been notified by ISO guidelines on the safe use of wastewater for irrigation, WHO's 2006 Water Reuse Guidelines, and regulatory plans in another country of the world. However, there is little harmonization between the water reuse standards proposed by the EU Member States. Consequently, this lack of harmonization has raised concerns that it could create some trade barriers to agricultural goods irrigated by reclaimed water in member states; simultaneously, the awareness of having different levels of safety for standards between these countries is at the core. This has resulted in low efficiency in water reuse activities, mainly due to the lack of uniform regulation at the European level regarding wastewater collection [57]. The quality of reused water shall be consistent among the Member States to achieve exceptional standards for agricultural products irrigated with treated wastewater. Therefore, to overcome this problem, the Joint Research Centre (JRC) was asked by the European Commission to develop a technical proposal on minimum quality requirements for the water reuse in irrigation, agriculture, and replenishment of groundwater to improve the water reuse as a focal element in the action plan of EU. The standards of JRC were released in an initial draft document in October 2016 and revised consistently in June 2017 [54]. Specific JRC standards are described in Appendices 1 and 2.

Most recently, on May 25, 2020, the European Commission announced new regulations on minimum requirements for the reuse of water for agricultural irrigation to provide comprehensive unity [55]. These new regulations went into effect, but the new guidelines will start June 26, 2023; These regulations are expected to stimulate and facilitate water reuse within the European Union [55]. They proposed the Regulation on Water Reuse to set minimum water risk management, monitoring, and quality requirements for the safe reuse of treated municipal wastewater to ensure child health, people, animals, and the environment, at the same time overcoming water scarcity. In which, the regulations include agricultural irrigation of raw food crops, non-food crops, and processed food crops. The proposal requires wastewater treatment plant operators to ensure that wastewater sources treated for reuse in irrigation and agriculture comply with a set of minimum requirements outlined in the proposal and any additional conditions imposed by the Member States. This recommendation defined the minimum requirements for the following parameters:

- Microbiological parameters: *Legionella*, *Escherichia coli* (*E. coli*), and intestinal nematodes (helminth eggs).
- Physical and chemical parameters: Biochemical Oxygen Demand 5 (BOD5), turbidity and total suspended solids (TSS).

These specific standards are detailed in Appendices 3 and 4.

The operators of the reclaimed plant must also prepare a Water Reuse Risk Management Plan based on essential risk management tasks such as identifying potential hazards, the environment, and the population present, risk assessment about environmental and human health, and identifying preventive measures. Besides, the proposal sets forth requests for information Member States could make available to the public regarding the wastewater reuse, such as quantity and quality of reclaimed water and proper permits, issuance and modification, and results of compliance tests derived from the Regulations. The implementation of these minimum requirements by the Member States will contribute to achieving the Sustainable Development Goals of the United Nations Agenda 2030 on Sustainable Development. The goal is to ensure the availability and management of water and sanitation for the global population and significantly promote safe water reuse and water recycling globally. Stronger guidelines and fiscal stimulus can make the farmers in Europe reuse more than 6,000 million cubic meters of the treated wastewater a year by 2025 [56].

6.2. Regulations in Member States

- Cyprus: in the country, the water stress is a severe problem. Cyprus depends on rainfall to save its water needs as surface water, and the resources of groundwater are limited. The country usually faces droughts, with frequency increasing over time due to climate change. Therefore, Cyprus determined the standards of water quality in 2005 for the reuse of wastewater. Cyprus is one of the first Member States with the provisions of the water reuse fully incorporated into the national law. Besides, replacing 40% of agricultural freshwater demand with the country's target reclaimed water [56]. Currently, treated wastewater is reused to irrigate agricultural land, public green areas, and parks [56]. Quality standards for reused water are set based on the source of treated wastewater. Furthermore, the Cyprus Good Agricultural Practices Code provides guidelines to ensure protecting community health and the environment. Simultaneously, the 'Water Pollution Control' legislation and related behaviours impose legally the values of binding limit for a wide domain of parameters that apply at the wastewater treatment plant. The quality requirements and the range values have been determined for more than twenty parameters for microbiological, physical, and chemical [56]. Cyprus does not use treated wastewater to irrigate leafy vegetables, fresh fruit and tubers, and exports. Compared to the proposal of European Commission, the laws of Cyprus include more uses for the Regulation on water reuse. Besides, the types of water reused and parameters to control are also more diverse. At the same time, compared with the recommendation of the European Commission, the monitoring frequencies that are set for some of these parameters are less stringent. In addition, the national framework of Cyprus does not provide any specific provisions for monitoring, planning, and managing risks. The law of Cyprus also does not make this information available to the public. These are the main drawbacks to water reuse regulations in Cyprus.

- France: France does not suffer from severe water stress. However, some regions in France have experienced water scarcity due to climate change issues, while some areas have increased the need for water in agriculture and irrigation. Consequently, France has adopted the standard of reusing water in the agricultural sector and irrigating green and recreational areas to address water needs. The legally binding standards of quality of the reclaimed water and the limit of risk management measures implemented by wastewater treatment plant operators were introduced in 2010 [57]. The limited standards for 6 parameters and the water reuse licensed for various crops, including fodder crops, flowers, fruit production, human food crops, and forests. But, it has limited to use public access. The following actions are prohibited by law in France: irrigation of mud or mud does not grant limited value to the purpose of farming; The irrigation water has passed through land processes that do not respond to the limitations of using mud in agriculture or in the protection breach near the water [57]. The human who runs the waste disposal has to perform a surveillance program including the data that uses water and the quality of the mud; they must also report the results to the mayor, mayor, and land users irrigated. Compared with the European Commission's proposal for the Regulation on water reuse, the French law is similar to the use, classification, and monitoring requirements of reused water. There are differences in the parameters monitored. Meanwhile, compared to requirements in EU regulations, requirements related to risk management and public information provision are not specific.
- Greece: Although Greece faces a lower water stress compared to the other Mediterranean countries, its territories face varying degrees of water scarcity. Furthermore, due to higher demand from agriculture and tourism in the mid-year period, water pressure to return water was more significant during this period [58]. The Greek Government adopted the standards and quality regulation for treating wastewater for various purposes such as agriculture, entertainment, and industry; however, the water reuse in Greece is still relatively low. It is attributed to the complexity of water reuse standards; standard parameters are specified very strictly. Illegal water exploitation is also one of the reasons. Besides, the people have not yet agreed to accept the issue of

water reuse. These are the reasons for the limited reuse of wastewater in Greece. Compared with the European Commission's proposal for Regulations on water reuse, the regulations of the country include more the propose uses, the parameters to control, and types of recycled water. Simultaneously, the monitoring frequency and the parameters are also different. Furthermore, the national framework does not provide. No specific provisions with verification monitoring, developing a risk management plan, and making information available to the public. Therefore, the Greek Government needs to develop more according to the European Commission's regulations to establish wastewater reuse.

- Italy: Italy is a country with water scarcity, especially in the south. Consequently, the reuse of water mainly for agricultural use has considered as a part of a long-term water management [56]. In Italy, national regulation gives the range standards for the applications in agricultural, industrial and urban. Compared to the European Commission for Water Reuse Regulations proposal, Italy's regulations are quite detailed regarding control and monitoring parameters. However, the Italian regulation does not differentiate water reuse into classes; although there are many defined parameters, all parameters in the proposal are determined, especially microbiological and disinfection parameters [56]. Furthermore, the national framework did not involve the requirements for making information available to the public, building a risk management plan, or monitoring confirmation. Therefore, the Government in Italy also needs to improve the regulations attached to the rules of the European Commission.
- Portugal: Water reuse is considered an indispensable part of sustainable development as Portugal is also experiencing water scarcity. Portuguese law in the form of standards regulations as the basis for licensing reuse. They become legally binding when they are included in a reuse license [56]. Quality levels correspond to those suggested by the Food and Agriculture Organization (FAO) guidelines for handling and use. The wastewater reuse is used in agriculture and refers to many different uses. The legislation in Portugal also stipulates that it is forbidden to irrigate vegetables with treated wastewater. Compared with the proposal of the European Commission for the water reuse regulation, the Portuguese framework is quite detailed regarding controlled and monitored parameters. But the Portuguese framework does not differentiate water use into classes, nor does it define all of the parameters in the proposal compared to the Commission. Furthermore, although the regulations include requests to make the information available to the public, these requirements do not correspond to suggestions. Similarly, the development of a monitoring or risk management plan is not included in existing regulations. These issues are the same for other countries. This requires Portugal also to improve their rules drastically.

- Spain: Spain is Europe's largest water reuse country by volume. Much of this water is used for agriculture because Spain is a relatively scarce country. Regulations on water reuse complement more comprehensive guidelines considered by the certain regions such as Andalusia, Catalonia, and Balearic Islands etc., [59]. The framework of national legal for water reuse in West Spain was quite advanced and offers comprehensive quality criteria. Legislation in Spain applies comprehensively to the presence of specific parameters by risk management measures and the types of water reuse. Besides, the analysis frequencies, the minimum sampling, and the requirements for the inclusion of a section on risk management measures have been planned. An implementation guide supplements national legislation; from there, they make recommendations on procedures and practices. Apparently, the Commission's proposal for water reuse regulations is similar to that of Spain. Similar parameters were given and applied to various types of water uses. However, Spanish laws are more detailed about the quality requirements, monitoring, and use of reclaimed water. Therefore, it can be seen that Spain is the member that best complies with the rules of the European Commission.
- Malta: This is one of the European countries most impacted by the most severe water stress [59]. Malta produces Class A reclaimed water that can be used for all food crops, including root crops and food crops. All irrigation methods are allowed. This is a strong move for Malta. The country is studying for the measures of new regulation to conduct the production and use of the handle wastewater and develop a public information system on treated wastewater quality to increase public acceptance.

From the above analysis, it can be seen that despite rising levels of water stress across the EU and great potential for reusing treated wastewater, water reuse is still limited and undesirable controls in the different Member States. Only a few European countries have introduced regulations on the reuse of wastewater. However, the regulations in these countries are not uniform. Besides, there are also restrictions in regulations in European countries. At the same time, the risk management and public communication plans are barely implemented. A few countries are in sync with the regulations of the European Commission, such as Spain, Malta. However, it also has limitations in regulations in these countries that need to be improved. Therefore, European countries need to consider their regulations; At the same time, they need to come up with measures to enhance regulations to encourage sustainable water reuse.

7. CONCLUSION AND RECOMMENDATION

7.1. Conclusion

From the analysis given above, this study provides conclusions by the following:

- The WEI and WSI indexes show that most European countries have low and moderate water stress levels, except in some countries such as Malta and Cyprus. Also, a country like Finland, Croatia, Norway, etc., practically does not have agents of water stress due to their availability of water. Compared to other European countries, Viet Nam also has relatively low water stress. However, due to its rapidly growing population and high water demand for domestic, industrial, and agricultural purposes, Vietnam could experience water stress and scarcity by 2030 without measures. Use water as appropriate. Compared with the European forecast for 2030, it can be seen that the freshwater scarcity in Vietnam is very serious due to the unsustainable use and exploitation of water.
- Due to the increasing water demand, European countries have launched efficient water reuse programs. Countries in Europe such as Spain, Cyprus, Bulgaria, Croatia, Malta, Slovenia, etc., have launched programs to reuse wastewater effectively in agriculture and irrigation. In particular, Spain is at the forefront of water reuse. Several European countries such as Cyprus and Malta have established water reuse as an important part of their management strategy due to frequent water shortages. Meanwhile, some countries such as Latvia, Lithuania, Finland, Denmark, Sweden, etc., do not face the problem of water stress due to having enough water supply; therefore, reusing treated wastewater is not considered a high priority. Therefore, the reuse of wastewater in Europe is still asynchronous between countries; It is necessary to have general rules for reusing wastewater. The issue of wastewater reuse in Vietnam is still very limited despite increasing water stress. Very few reports mention wastewater reuse in Vietnam. This may also be due to the lack of modern water treatment technology in Vietnam; it cannot meet water standards for reuse for different purposes. Therefore, the government should have measures to manage and encourage the reuse of wastewater.
- Advanced technologies need to be applied to ensure that the treated water meets the standards for reuse for different purposes. Many advanced technologies have been studied and used in wastewater treatment in European countries such as ozonation, activated carbon adsorption, chemical disinfectants, UV radiation, advanced oxidation process, and membrane filtration. These technologies all have certain advantages and disadvantages. Several technologies effective for CEC treatment are present in wastewater, while a number of technologies have proved

effective for disinfection and disinfection. Besides, the creation of hazardous by-products or high operating costs is also limited to some technologies. Therefore, combining these advanced technologies in wastewater treatment plants in addition to traditional technologies is a requirement.

- In order to encourage and improve water reuse, the European Commission has announced new rules for water reuse to provide comprehensive unity. However, only a few European countries have introduced regulations on the reuse of wastewater. However, the regulations in these countries are not uniform. Besides, there are also restrictions in regulations in European countries. Therefore, countries in Europe need to take measures to improve their regulations that are consistent with those of the European Commission to encourage sustainable water reuse.

7.2. Recommendation

From the analysis given above, this study provides recommendations by the following:

- With the current increasing water stress, European countries need to improve and increase water reuse for sustainable development.
- To be able to reach the water standards issued by the European Commission, European countries need to apply advanced technologies in wastewater treatment plants in addition to traditional technologies. The advanced technologies and proposed models can be researched and applied practically to raise standards in wastewater reuse.
- Countries need to have uniform standards of wastewater treatment compared with the regulations of the European Commission. Governments need to take measures to establish regulations for countries that have not yet developed standards for wastewater reuse.
- For Vietnam, water tensions are increasing with population growth. However, the issue of wastewater reuse is hardly mentioned in Vietnam. The causes leading to this situation: wastewater treatment technologies do not meet the standards in water reuse. The government does not have a deep concern; people are not aware of the reuse of wastewater. Therefore, the Government of Vietnam needs to put in place appropriate regulations to encourage and increase wastewater reuse. This helps towards sustainable water use and management.

SUMMARY

This study analysed the current situation of water reuse in European countries and compared it with Vietnam. Water stress indices were assessed by WEI and WSI. The results show that European countries have primarily low or moderate water stress index, besides some countries with high water stress index such as Cyprus or Malta. The countries in the Nordic region with abundant water resources do not experience water stress. Vietnam also has relatively low levels of water stress compared to European countries. However, with population growth and climate change, Vietnam will become a country with water scarcity in the future.

Water reuse data in Europe shows that a number of European countries have viewed water reuse as one of the solutions for sustainable water management. However, water reuse in Europe is not synchronous. Some countries do a relatively good job of reusing water, while others have barely mentioned it. Typical European countries such as Spain, France, Cyprus, Malta, Portugal, Italy, etc., are concerned with water reuse. In particular, Spain is the leading country in the reuse of wastewater by volume. Some countries with water scarcity, such as Cyprus, Malta, Italy, etc., also consider wastewater reuse one of the top priorities. Globally, Europe has a relatively high rate of wastewater reuse, but it is not synchronous. Compared to other European countries, Vietnam hardly has a good interest in wastewater reuse. However, there are very few studies on wastewater reuse in Vietnam. This raises concerns about serious water scarcity for Vietnam in the future. The reason is attributed to: the Government does not have proper regulations on wastewater reuse; advanced wastewater treatment technologies have not been applied in wastewater treatment plants, resulting in wastewater ineligible for reuse; People are not really interested in wastewater reuse.

Advanced technologies in wastewater treatment have been introduced to meet the standard requirements for wastewater reuse. These advanced technologies include ozonation, activated carbon adsorption, chemical disinfectants, UV radiation, advanced oxidation process, and membrane filtration. These technologies all offer certain advantages and disadvantages. Some techniques are effective for treating CEC in wastewater, while some are effective for disinfection and disinfection. Besides, some technologies work for both but either create toxic byproducts or too high operating costs. Therefore, in order for the treated effluent to comply with all the standards of the European Commission, a combination of these advanced technologies and traditional technologies is necessary. The models discussed in this study provide new solutions for wastewater treatment.

The European Commission has set out regulations to develop and reuse wastewater between countries synchronously. The analysis results clearly show that only a few countries have regulations on the reuse of wastewater. Some other countries hardly have any regulations on this issue. However, it is the fact that there is no uniformity in the regulations of the countries compared with the regulations of the European Commission. A few countries that are giving relatively consistent regulations to the Commission are Spain and Malta. However, these regulations also have certain limitations. Therefore, to develop wastewater reuse and meet the set objectives, Governments of member states need to adjust the regulations according to the rules of the European Commission nomination. At the same time, it is also necessary to improve management, encourage and develop the reuse of wastewater towards sustainable development.

LIST OF REFERENCES

1. Elgallal, M., L. Fletcher, and B. Evans, *Assessment of potential risks associated with chemicals in wastewater used for irrigation in arid and semiarid zones: A review.* Agricultural Water Management, 2016. **177**: p. 419-431.
2. *https://www.worldvision.org/clean-water-news-stories/global-water-crisis-facts*. World Vision 2017.
3. *European Comission, https://ec.europa.eu/environment/water/reuse.htm*.
4. Maass, O. and P. Grundmann, *Added-value from linking the value chains of wastewater treatment, crop production and bioenergy production: A case study on reusing wastewater and sludge in crop production in Braunschweig (Germany).* Resources, Conservation and Recycling, 2016. **107**: p. 195-211.
5. Akpan, V.E., D.O. Omole, and D.E. Bassey, *Assessing the public perceptions of treated wastewater reuse: opportunities and implications for urban communities in developing countries.* Heliyon, 2020. **6**(10): p. e05246.
6. Salgot, M. and M. Folch, *Wastewater treatment and water reuse.* Current Opinion in Environmental Science & Health, 2018. **2**: p. 64-74.
7. *Water Reuse Europe, https://www.water-reuse-europe.org/about-water-reuse/policy-and-regulations/#page-content.*
8. Amec Foster Wheeler Environment & Infrastructure UK Ltd, I., ACTeon, IMDEA and NTUA, *EU-level instruments on water reuse*. 2016: Luxembourg: Publications Office of the European Union.
9. *EUROSTAT, Available: ec.europa.eu/eurostat*.
10. *One World Nations Online, https://www.nationsonline.org/oneworld/vietnam.htm.*
11. *THE WORLD BANK DATA, https://data.worldbank.org/country/*. 2019.
12. Oertlé, E., et al., *Potential for water reuse in Vietnam.* Journal of Vietnamese Environment, 2019. **11**(2): p. 65-73.
13. Group, W.B., *Vietnam: Toward a Safe, Clean, and Resilient Water System*. 2019: World Bank.
14. Nepomilueva, D., *Water scarcity indexes Water availability to satisfy human needs*. 2017, Helsinki Metropolia University of Applied Sciences.
15. *"AQUASTAT," http://www.fao.org/aquastat/statistics/query/index.html.*
16. *THE WORLD BANK DATA, https://data.worldbank.org/country/vietnam*.
17. *AQUASTAT database, http://www.fao.org/nr/water/aquastat/data/query*.
18. Bisselink B., et al., *Climate change and Europe's water resources*. 2020: Joint Research Centre.
19. Rebelo, A., et al., *Report on Urban Water Reuse*. 2018: IMPEL General.

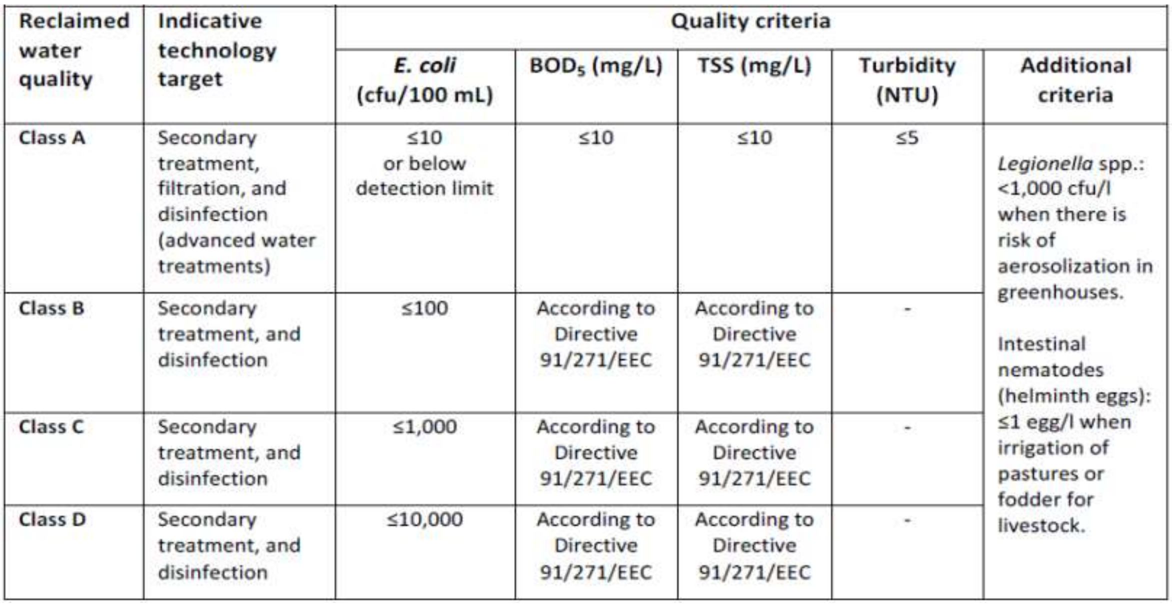
20. *REGULATION (EU) 2020/741 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 May 2020 on minimum requirements for water reuse*. 2020: Official Journal of the European Union. p. 32-55.
21. Brussels, *Report From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions Directive 91/271/EEC*. 2020.
22. Directors, E.W., *Guidelines on Integrating Water-reuse into Water Planning and Management in the context of the WFD.* Common Implementation Strategy for the Water Framework directive and the foods directive, 2016.
23. Anabela Rebelo, Geneve Farabegoli, and F. Andreotti, *Report on Urban Water Reuse*. 2018: IMPEL, Austria.
24. *EU-level instruments on water reuse: Final report to support the Commission's Impact Assessment*. 2016: European Union.
25. Desa, U., *Transforming our world: The 2030 agenda for sustainable development.* 2016.
26. Elkiran, G., F. Aslanova, and S. Hiziroglu, *Effluent water reuse possibilities in Northern Cyprus.* Water, 2019. **11**(2): p. 191.
27. Jodar-Abellan, A., M.I. López-Ortiz, and J. Melgarejo-Moreno, *Wastewater treatment and water reuse in Spain. Current situation and perspectives.* Water, 2019. **11**(8): p. 1551.
28. Rebelo, A., et al., *Water reuse in Portugal: New legislation trends to support the definition of water quality standards based on risk characterization.* Water Cycle, 2020. **1**: p. 41-53.
29. Jones, E.R., et al., *Country-level and gridded estimates of wastewater production, collection, treatment and reuse.* Earth System Science Data, 2021. **13**(2): p. 237-254.
30. Evans, A. *Policy support for wastewater use in Hanoi*. in *Sustainable water and sanitation services for all in a fast changing world: Proceedings of the 37th WEDC International Conference, Hanoi, Vietnam*. 2014. cc WEDC, Loughborough University.
31. Lan, A., et al., *Wastewater reuse in Thanh Tri district, Hanoi suburb, Vietnam.* Hanoi: Hanoi University of Civil Engineering, 2012.
32. G. Bergkamp and N.V. Anh, *WASTEWATER MANAGEMENT AND RESOURCE RECOVERY IN VIETNAM*. 2018: ARCOWA.
33. *QCVN 14:2008/BTNMT*, M.o.N.R.a. Environment, Editor. 2008.
34. *QCVN 40:2011/BTNMT*, V.M.o.N.R.a. Environment, Editor. 2011.
35. *QCVN 08:2015/BTMT* V.M.o.N.R.a. Environment, Editor. 2015.

36. Rizzo, L., et al., *Best available technologies and treatment trains to address current challenges in urban wastewater reuse for irrigation of crops in EU countries.* Science of the Total Environment, 2020. **710**: p. 136312.
37. Bourgin, M., et al., *Evaluation of a full-scale wastewater treatment plant upgraded with ozonation and biological post-treatments: Abatement of micropollutants, formation of transformation products and oxidation by-products.* Water research, 2018. **129**: p. 486-498.
38. Von Sonntag, C., *The basics of oxidants in water treatment. Part A: OH radical reactions.* Water science and technology, 2007. **55**(12): p. 19-23.
39. Alexander, J., et al., *Ozone treatment of conditioned wastewater selects antibiotic resistance genes, opportunistic bacteria, and induce strong population shifts.* Science of the Total Environment, 2016. **559**: p. 103-112.
40. Rizzo, L., et al., *Advanced treatment of urban wastewater by sand filtration and graphene adsorption for wastewater reuse: Effect on a mixture of pharmaceuticals and toxicity.* Journal of environmental chemical engineering, 2015. **3**(1): p. 122-128.
41. Michael, S.G., et al., *Solar photo-Fenton oxidation followed by adsorption on activated carbon for the minimisation of antibiotic resistance determinants and toxicity present in urban wastewater.* Applied Catalysis B: Environmental, 2019. **244**: p. 871-880.
42. Rizzo, L., et al., *Consolidated vs new advanced treatment methods for the removal of contaminants of emerging concern from urban wastewater.* Science of the Total Environment, 2019. **655**: p. 986-1008.
43. Li, B. and T. Zhang, *Mass flows and removal of antibiotics in two municipal wastewater treatment plants.* Chemosphere, 2011. **83**(9): p. 1284-1289.
44. Gao, S., et al., *Oxidation of sulfamethoxazole (SMX) by chlorine, ozone and permanganate—A comparative study.* Journal of Hazardous Materials, 2014. **274**: p. 258-269.
45. Formisano, F., et al., *Inactivation of Escherichia coli and Enterococci in urban wastewater by sunlight/PAA and sunlight/H_2O_2 processes.* Process Safety and Environmental Protection, 2016. **104**: p. 178-184.
46. Nurizzo, C., et al., *By-products in surface and reclaimed water disinfected with various agents.* Desalination, 2005. **176**(1-3): p. 241-253.
47. Rizzo, L., et al., *Tertiary treatment of urban wastewater by solar and UV-C driven advanced oxidation with peracetic acid: Effect on contaminants of emerging concern and antibiotic resistance.* Water research, 2019. **149**: p. 272-281.

48. Yuan, F., et al., *Photodegradation and toxicity changes of antibiotics in UV and UV/H_2O_2 process.* Journal of hazardous materials, 2011. **185**(2-3): p. 1256-1263.
49. Stasinakis, A., *Use of selected advanced oxidation processes (AOPs) for wastewater treatment—a mini review.* Global NEST journal, 2008. **10**(3): p. 376-385.
50. Chan, S.H.S., et al., *Recent developments of metal oxide semiconductors as photocatalysts in advanced oxidation processes (AOPs) for treatment of dye waste‐water.* Journal of Chemical Technology and Biotechnology, 2011. **86**(9): p. 1130-1158.
51. Sannino, D., et al., *Wastewater treatment by high efficiency heterogeneous photo-Fenton process*. 2008, Google Patents.
52. Maniakova, G., et al., *Comparison between heterogeneous and homogeneous solar driven advanced oxidation processes for urban wastewater treatment: Pharmaceuticals removal and toxicity.* Separation and Purification Technology, 2020. **236**: p. 116249.
53. Garcia, N., et al., *The application of microfiltration-reverse osmosis/nanofiltration to trace organics removal for municipal wastewater reuse.* Environmental technology, 2013. **34**(24): p. 3183-3189.
54. Alcalde-Sanz, L. and B. Gawlik, *Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge.* Towards a legal instrument on water reuse at EU level, 2017.
55. *REGULATION (EU) 2020/741 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*. 2020.
56. by Deloitte, B., *Optimising water reuse in the EU–Final report prepared for the European Commission (DG ENV), Part I.* collaboration with ICF and Cranfield University, 2015.
57. Drewes, J.E., et al., *Characterization of unplanned water reuse in the EU.* Publications Office of the European Union: Luxembourg, 2017.
58. *EU-level instruments on water reuse, Final report to support the Commission's Impact Assessment*. 2016: Amec Foster Wheeler Environment & Infrastructure UK Ltd, IEEP, ACTeon, IMDEA and NTUA.
59. *Water reuse - legislative Framwork in EU Regions*. 2018: European Committee of the Regions.

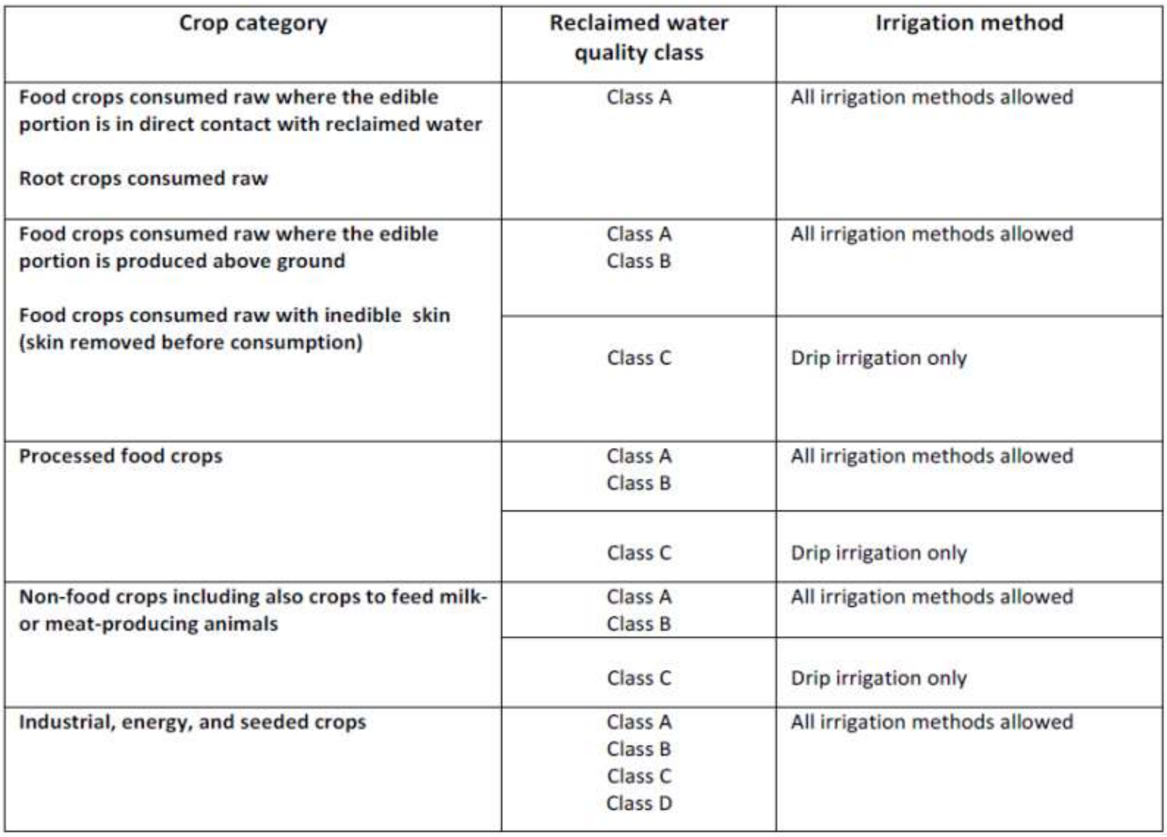
APPENDICES

APPENDICE 1. Minimum quality requirements for reclaimed water in agricultural irrigation of JRC



Reclaimed water quality	Indicative technology target	Quality criteria				
		E. coli (cfu/100 mL)	BOD_5 (mg/L)	TSS (mg/L)	Turbidity (NTU)	Additional criteria
Class A	Secondary treatment, filtration, and disinfection (advanced water treatments)	≤10 or below detection limit	≤10	≤10	≤5	*Legionella* spp.: <1,000 cfu/l when there is risk of aerosolization in greenhouses. Intestinal nematodes (helminth eggs): ≤1 egg/l when irrigation of pastures or fodder for livestock.
Class B	Secondary treatment, and disinfection	≤100	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	
Class C	Secondary treatment, and disinfection	≤1,000	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	
Class D	Secondary treatment, and disinfection	≤10,000	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	

APPENDICE 2. Classes of reclaimed water quality and associated agricultural uses of JRC



Crop category	Reclaimed water quality class	Irrigation method
Food crops consumed raw where the edible portion is in direct contact with reclaimed water **Root crops consumed raw**	Class A	All irrigation methods allowed
Food crops consumed raw where the edible portion is produced above ground **Food crops consumed raw with inedible skin (skin removed before consumption)**	Class A Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Processed food crops	Class A Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Non-food crops including also crops to feed milk- or meat-producing animals	Class A Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Industrial, energy, and seeded crops	Class A Class B Class C Class D	All irrigation methods allowed

APPENDICE 3. Minimum quality requirements for reclaimed water in agricultural irrigation of European Commission

<table>
<tr><th rowspan="2">Minimum Quality Class</th><th rowspan="2">Indicative Technology Target</th><th colspan="4">Quality Requirements</th></tr>
<tr><th>Escherichia coli [No./100 mL]</th><th>Biological Oxygen Demand [mg/L]</th><th>Total Suspended Solids [mg/L]</th><th>Turbidity [NTU]</th></tr>
<tr><td>A</td><td>Secondary treatment, filtration and disinfection</td><td>≤10</td><td>≤10</td><td>≤10</td><td>≤5</td></tr>
<tr><td>B</td><td>Secondary treatment and disinfection</td><td>≤100</td><td colspan="2" rowspan="3">In accordance with Directive 91/271/EEC</td><td>-</td></tr>
<tr><td>C</td><td>Secondary treatment and disinfection</td><td>≤1000</td><td>-</td></tr>
<tr><td>D</td><td>Secondary treatment and disinfection</td><td>≤10,000</td><td>-</td></tr>
</table>

APPENDICE 4. Classes of treated water quality, by agricultural use and irrigation method of European Commission

Minimum Quality Class	Categories of Agricultural Crops	Irrigation Method
A	All food crops consumed raw where the edible part is in direct contact with treated water and root crops consumed raw	All irrigation methods
B	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with treated water, processed food crops and non-food crops including crops used to feed milk or meat-producing animals	All irrigation methods
C	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with treated water, processed food crops and non-food crops used to feed milk or meat-producing animals	Drip irrigation 2 or other irrigation methods that avoid direct contact with the edible part of the crop
D	Industrial, energy and seeded crops	All irrigation methods