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Review
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A SOLUTION TO WASTE ECONOMY AND WATER SCARCITY; AIR CONDITIONING WASTEWATER

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Abstract: The waste economy, which is based on the use of wastes that are previously produced and/or produced during the production/consumption process and contain valuable substances for production and pose a significant threat to nature, humans and other living beings, as an alternative to depleting production resources, is a mandatory activity that must be implemented. The waste economy is the process of obtaining production inputs necessary to meet human needs from wastes. The aim of this study is to examine whether wastewater produced by air conditioners at zero cost can be used as an alternative water source to meet the increasing water demand. The study method is the literature review method and scientific studies on the subject, academic publications, digital resources, documents, reports, opinions and evaluations published by authorized and expert national/international persons, institutions and organizations on the subject were used as the study material. The study findings support the fact that waste is an important source of raw materials when evaluated correctly, and that the costs incurred to manage these wastes are instantly transformed into production investments (waste recycling revenue in the world in 2020 was 135 billion dollars). Similarly, the study findings support the fact that evaluating air conditioning wastewater will create significant economic value. Tons of water produced by approximately 2 billion air conditioners in the world (a 1-ton air conditioner produces 1.10 litres of wastewater per hour) and used for various purposes such as drinking and irrigation, which should be used for the economy, are wasted. According to the study findings, wastes (water, plastic, electronics, organic, etc.), which could provide significant economic gains but are not evaluated and cause great economic losses and costs, provide strong evidence that they will be a source of raw materials that meet our needs.

Keywords: Waste, Waste management, Waste economy, Air conditioners, Air conditioner wastewater

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1. Introduction

In order to sustain their existence, people have to meet their material and spiritual needs that arise at various levels, either directly or indirectly, through production activities consisting of a series of exchange and transformation processes consisting of various economic processes, using scarce resources in nature (air, water, soil, minerals, all living and non-living entities) (Sırım, 2018). Due to the rapid depletion of scarce natural resources used to meet human needs, the search for alternative solutions to reduce the pressure on these resources (Wang et al., 2023; EC, 2023), and to protect, improve and develop the current status of these resources, thus creating a sustainable production/consumption structure, is becoming increasingly important (Sayğı, 2023). On the one hand, the inputs (raw materials) required for production processes must be produced continuously in order to meet human needs (Lahmo, 2024), while on the other hand, these raw material resources (nature) are rapidly consumed due to excessive use and cause great damage to the natural balance (Sayğı, 2023).

In this sense, the evaluation of the wastes of manufactured products or the wastes generated in various production/consumption processes in the supply of inputs needed in the production process has become an important field of economic activity (Mısır and Arıkan, 2023). These activities, expressed with the concept of circular economy, are the most important starting point and component of sustainable economic activities (Mandpe et al., 2022). Sustainable economic activities should foresee the costs incurred in the production/consumption processes and environmental costs (Sayğı, 2023). In this sense, one of the most important environmental costs is waste that poses a threat to nature, humans and other living beings (Sayğı, 2022; Mishra et al., 2023). While the re-use of these wastes as inputs in the production process required high costs until a certain period, rapidly developing technology has made these costs bearable and even more profitable in some cases (Mashudi et al, 2023). One of the main objectives of sustainable economic activities is to destroy and/or preserve these wastes correctly if they cannot be used; and to evaluate them correctly if they can be used and to direct them back to production processes as a production input (Güllü, 2023).

The scarcity and rapid consumption of natural resources that meet human needs, and the constraints related to the necessity of continuously providing these resources to the production process are important problems waiting for solutions. On the other hand, the production of these resources causes great damage to nature, and these damages pose a threat to the existence of nature, humans and other living beings (Mashudi et al., 2023; Mishra et al., 2023). These problems have made wastes, which can be converted into raw materials that can be used in the production process at lower costs with the developing technology, very valuable as a new raw material source (Mishra et al., 2023). In the new economic process, waste management (return, rethink, reduce, recycle and reuse) has created the circular economy model, which is an important area of economic activity, by transforming the waste taken from consumption points into very valuable raw materials through the reverse logistics chain (Güllü, 2023; Mısır and Arıkan, 2023). The circular economy model not only provides added value by producing the raw materials needed by production processes at a more affordable cost, but also, more importantly, eliminates the environmental costs of these wastes (Güllü, 2023; Mısır and Arıkan, 2023).

Sustainable economic activities are the design of production/consumption processes that protect, improve and develop nature, humans and other living beings. In this sense, waste management processes have gained importance in order to preserve, destroy and recycle the wastes generated in the production/consumption processes in accordance with sustainable purposes. Wastewater management is the management processes that find application areas in order to evaluate every drop of water, which is a scarce and vital resource, to protect natural water resources and to purify polluted water. In this sense, it covers the processes of recycling and purifying water used in domestic, industrial and agricultural production/consumption activities for various purposes without harming nature, humans and other living beings. Thanks to wastewater management, water resources are protected and the clean water needs of future generations are also met. In order to protect a sustainable environment and natural ecosystem, wastewater management is supported by governments and the private sector. It can be said that conscious initiatives in the world and in Türkiye regarding wastewater management can be considered very new and insufficient (Saraoğlu, 2014). The first legal document in the world on wastewater management is the 'Reuse of effluents: methods of wastewater treatment and health safeguards' document published by the World Health Organization (WHO) in 1973 as a guideline for the protection of water resources and public health (WHO, 1973). The guideline document 'Health guidelines for the use of wastewater in agriculture and aquaculture' was published in 1989, based on this document (WHO, 1989). In the United States of America (USA), the California Title 22 criteria published in 1978 by the State of California (CCR, 1978), and the wastewater use guide documents 'Waste Water Treatment Manuals' published by the Environmental Protection Agency (EPA) in 1992 (EPA, 1992), the EU Water Framework document numbered 2000/60/EC published by the European Union (EU) in 2000, and the 'Water Pollution Control Regulation' in 2004 and the 'Urban Wastewater Treatment Regulation' in 2006 based on the Environmental Law numbered 2872 in Türkiye are legal regulations regarding wastewater management (Saraoğlu, 2014). Pressure of the conscious society and the regulations in the legal field have made wastewater management mandatory. With wastewater management, wastewater does not harm nature, humans and other living beings, and the sustainable use of water resources is ensured by protecting, improving and developing water resources. There are traditional methods consisting of physical, chemical and biological treatment processes in the evaluation of wastewater in wastewater management (Xu et al. 2020; Kulkarni, 2023). Nanotechnology, biotechnology and membrane technologies are used to make wastewater treatment processes more effective and efficient (Kulkarni, 2023). In this way, wastewater is evaluated quickly and at a low cost and in accordance with the purpose. In order for these processes to be successful, it is necessary to create social awareness in water use (Saraoğlu, 2014).

As water resources are insufficient to meet the water needs of the increasing human population, the evaluation of wastewater produced by air conditioners within the scope of wastewater management has become the subject of scientific studies. The findings obtained in these studies indicate that wastewater produced by air conditioners should be evaluated (Matarneh et al., 2024).

This study was conducted to examine whether the wastewater produced by air conditioners used in ambient climate control will provide a solution to the increasing water demand.

2. Review

In this study conducted on whether air conditioners used to control the ambient climate conditions in buildings used for various purposes will meet the increasing water demand, literature review was used as a research method. The research data set was formed from scientific studies, academic studies, journals, digital publication sources on the subject; publications of national/international experts, private and public institutions and organizations on the subject, and documents in which their opinions were published. Accordingly, firstly waste economy, amount of waste water produced by air conditioners, water quality, water usage possibilities were examined.

3. Waste Economy

One of the most important stages of sustainable economic activities is the proper disposal, preservation and evaluation of wastes arising from various production/consumption processes in terms of managing their environmental costs (Sayğı, 2023). In this process, it is expressed as waste economy as a result of the activities carried out especially for the purpose of re-evaluating the wastes and bringing them into the production process (Seyhan, 2023). As it is understood that natural raw material resources are being depleted and that using these resources is no longer sustainable, the components in previously produced products that have become waste have begun to gain value as new raw material resources (Usón, 2013). Table 1 shows the economic data of the waste economy in the world, the United States of America (USA), the European Union (EU) and Türkiye.

Table 1. Estimated economic value of waste economy in the world, USA, EU and Türkiye

Estimated	*UN Unit Income/Cost (USD)	World 2020 (USD)	USA 2018 (USD)	EU 2018 (USD)	Türkiye 2020 (USD)
Direct economic cost	118.67	252,300,000,000.00	34,700,150,517.40	27,734,012,229.54	12,436,989,651.93
Indirect economic cost	114.44	243,300,000,000.00	33,462,333,019.76	26,744,689,557.86	11,993,339,604.89
Recycling earned	202.39	135,600,000,000.00	29,589,134,328.36	25,824,756,895.52	11,941,381,253.73
Annual cost net	169.80	361,000,000,000.00	49,650,235,183.44	39,682,831,608.65	17,795,296,331.14
Total amount of waste (tons)		2,126,000,000.00	292,400,000.00	233,700,000.00	104,800,000
Amount recovered (tons)		670,000,000.00	146,200,000.00	127,600,200.00	59,002,400
Number of jobs created (units)		6,300,000.00	681,000.00	700,000.00	350,000

*Unit cost/income values were obtained by proportioning the waste amounts to the UN waste values. UN= United Nations; USA= United States of America; EU= European Union.

According to Table 1, the total volume of the waste economy in the world and Türkiye according to the United Nations (UN) unit values in 2020 was approximately 495 billion dollars (UNEP, 2024) and 24 billion dollars (TÜİK, 2024), respectively. According to the UN environmental program report, the amount of solid waste collected by municipalities, which was 2.126 billion tons in 2020, is estimated to increase by 56% and reach 3.8 million tons in 2050 (UNEP, 2024). Based on 2020, 810 million tons of this amount was thrown into the environment or burned (uncontrolled), 400 million tons was recycled and re-evaluated, 640 million tons was stored in landfills and 270 million tons was burned and used in energy production (UNEP, 2024). According to 2018 data in the USA, 292 million tons of municipal solid waste were collected, approximately 69 million tons of this amount was recycled, 25 tons were used in compost production, 17.7 million tons were used with different methods and 35 million tons were used in energy production, a total of 146.7 million tons were recycled into the economy and the remaining 146 million tons were placed in landfills (EPA, 2020). According to 2018 data in the USA, the income from the waste economy was 106.83 billion dollars and 145.7 billion dollars in 2023 (statista, 2024). According to 2018 data in EU countries, 233.7 million tons of municipal solid wastes were collected, 37.9% of this amount was recycled, 10.7% was refilled and 6% was used for energy production, a total of 54.6% was recycled and reintroduced to the economy (Magazzino and Falcone, 2022). In 2020, 56.3% of the total waste in Türkiye was evaluated in the recycling process, 24.2% in regular storage areas, 14.1% in the workplace area/within the facility producing the waste, 3.2% within the management of municipalities or organized industrial zones, 1.7% in incineration facilities, 0.4% in nature as filling material, and 0.1% in different areas with other methods (TÜİK, 2024).

The waste economy is divided into important sub-branches in terms of waste type and has created unique features. One of these sub-branches and an important area is plastic waste, which is one of the most damaging waste types to the environment, and is a very valuable waste type suitable for processing. According to a report by WWF in 2019, annual plastic production is approximately 200 million tons and about half of this amount is evaluated incorrectly, 11 million tons of waste is thrown into the environment every year and the damage this waste causes to nature, humans and other living beings has a cleaning cost of 3.7 trillion dollars as a measure (WWF, 2021). Nayanathara et al. (2024) reported that an estimated 6.30 billion tons of plastic materials were produced between 1950 and 2015, approximately 80% of these materials were dumped into the natural environment, and it takes 100 to 1000 years for these plastics to break down and transform in the natural environment. According to 2018 data, the annual cleaning cost of plastic waste dumped into the environment could be up to 15 billion dollars, the cleaning cost of plastic waste accumulated in the seas alone is 7 billion dollars, and according to 2019 data, the management cost of all plastic waste is estimated to be 32 billion dollars annually (WWF, 2021). The export value of waste plastics, one of the important components of the circular economy, was 254 million tons of plastic waste between 1988 and 2022, with an import value of 8.8 billion dollars and a total trade volume of 20.4 billion dollars (Xu et al. 2020).

Electronic waste is another important type of waste. According to a report published by the UN, as of 2019, 53.6 million tons of electronic waste were generated in the world, and only 17% of this waste (total economic value of 10 billion dollars recovered) can be collected and utilized, while a large portion of 83% cannot be utilized (Forti, 2020; WEF, 2023). Scientific studies have shown that the annual value of electronic waste on a global scale is approximately 62.5 billion dollars (Ali and Shirazi, 2023). 90% of electronic waste consists of the most widely used metals, such as iron, copper, tin and aluminium, which provide high added value from recycling these wastes, while metals such as palladium and platinum, which are relatively less in quantity but have the highest value, increase this added value even more (WEF, 2023). The American Coalition for Electronics Recycling (CAER) estimates that the need to recycle waste computers will require approximately 42,000 jobs annually and will add more than $1 billion in economic value to this workforce (Rabbi, 2021).

Another important type of waste is organic waste. Organic waste consists of plant and animal wastes generated during agricultural production, household wastes generated from household consumption, and industrial wastes generated during the production of goods (Sayğı, 2023). The vast majority of organic waste is household waste (49%), and the vast majority of this waste is food (39%). Food worth 940 billion dollars (1/3 of total food production; 1.3 billion tons) is thrown away every year in the world (Ricci-Jürgensen et al., 2020). According to 2016 data, the total annual amount of domestic waste in the world is 2,017 million tons; 935 million tons of this amounts consists of organic waste (Ricci-Jürgensen et al., 2020), however, 19% of municipal solid waste in the world is recycled (UNEP, 2024). If 33% of this amount (309 million tons year^{-1}) is made into organic plant nutrition fertilizer compost and applied to the soil at an amount of 10 tons ha^{-1}, approximately 31 million ha of land can be cultivated, representing 2.4% of the total agricultural land in the world (Ricci-Jürgensen et al., 2020). In Türkiye, approximately 30 million tons of household waste is recycled annually, contributing 10 billion TL to the country's economy (Kök, 2021). Scientific studies have proven that fertilizers produced from organic waste not only eliminate organic matter deficiency caused by faulty agricultural production methods, but also improve soil quality by regulating the chemical and physical structure of the soil (Sayğı, 2022)

There are costs that must be incurred for the proper disposal, preservation and recycling of wastes, the protection, improvement and development of nature, humans and other living beings, and the creation of a sustainable economic structure (Sayğı, 2022). These costs, which are inevitably incurred, can be transformed into investments that serve the purpose of production with the circular economy (sustainable economic structure). It is estimated that coal, from non-renewable natural resources, will meet the demand under current conditions for 188 years, oil for 46.2 years, and natural gas for 58.6 years (The World Counts, 2024). As the scarce resources in nature used to meet human needs are rapidly depleted, the wastes resulting from various production/consumption processes have great potential as a new production raw material source. As a result, when non-resource and external benefits are taken into account, it is estimated that the circular economy will produce a total economic value of 1.8 trillion EURO (Biniş, 2023).

Although water, a vital resource, covers 70% of the world's surface, the majority of this amount is in the form of ice at the poles, and 2.5% is freshwater (Mishra, 2023; The World Counts, 2024). According to 2020 data, approximately 26% of the world's population (2 billion people) did not have access to safe drinking water, and 46% (3.6 billion people) did not have access to clean water resources (Unesco, 2023). According to Food and Agriculture Organization (FAO) data, it is estimated that 34% of the world's countries will experience water stress, 15% will experience water scarcity, and 40% of the world's population, which is estimated to be 9.4 billion in 2050, will experience water shortages (Koşar, 2024). In Türkiye, which is among the countries that will experience water stress, it is estimated that with the increasing population, the annual amount of usable water per capita will decrease to 1,200, 1,116 and 1,069 cubic meters in 2030, 2040 and 2050, respectively, and Türkiye will become a country suffering from water scarcity (WWF, 2023). Water and water resource scarcity is one of the most important problems awaiting solutions in the coming years. In this sense, whether wastewater produced by air conditioners within the scope of the waste economy will provide a solution to this problem has been and is being the subject of various scientific studies.

4. Amount of Wastewater Produced by Air Conditioners

Air conditioners, which were offered to people with the patent of "Air Processing Apparatus" by Engineer Willis Carrier, who played an important role in the first emergence of the idea of artificial cooling, are one of the indispensable comfort-providing tools of modern life (ENERGY.GOV, 2015). As with every technological innovation that makes human life easier and increases comfort, air conditioners also have negative effects on human health and nature (Elveren et al., 2018), although the use of air conditioners continues to increase (Khan et al., 2018). Approximately 4% of global greenhouse gas emissions that cause climate change are caused by air conditioners, which consume 10% of global electricity (Elveren et al., 2018; Woods et al., 2022). When air conditioners are not used correctly, they affect human health and cause skin dryness, respiratory dysfunction, cardiovascular diseases, and constant physical fatigue

(Khan et al., 2018). Despite this, since the benefit produced by the use of air conditioners is greater, their production and use are increasing (Dünya Gazetesi, 2024). As the pressure on natural resources that meet human needs increases and these resources are depleted, the use of previously produced and inactive wastes in meeting human needs is seen as an economical solution (Wang and Azam, 2024). Similarly, water resources, one of the scarce resources in the world, are rapidly depleting, becoming polluted, or the cost of accessing water is increasing (Yıldız, 2016). This situation has brought air conditioner wastewater to the agenda as a new water source to meet the increasing water demand.

Snidvongs and Vongsumran (2020) investigated the possibility of using wastewater produced by air conditioners as safe drinking water for humans, and observed that a 1 horsepower (0.58-0.67 ton; 12000 BTU = 1 ton) air conditioner can produce approximately 9 litres of water in 6 hours in a high humidity environment (Guarnieri et al. 2023, 40-60% normal humidity). AlGhamdi et al. (2024) investigated the quality of wastewater produced by different types of air conditioners, and observed that a window air conditioner operated for 8 hours per day in the low temperature and high humidity southern region of Jeddah City, Saudi Arabia, produced 8,725 litres of water per year, and a split air conditioner produced 20,614 litres of water per year. Sabnis et al. (2020) reported in their study examining the quality and usage possibilities of air conditioning wastewater that modern air conditioners generally produce 15-70 litres per day, depending on the air conditioning capacity and the amount of relative humidity in the air, and that a 1 ton air conditioner operating for 7-8 hours can produce up to 10 litres of pure water when collected under aseptic conditions. Sabnis et al. (2020) reported that approximately 6 million active air conditioners in residential and commercial premises in India produce approximately 50-100 million litres of wastewater per day for most of the year and that this resource should be utilized.

Scalize et al. (2018) studied the usability of air conditioner wastewater in a laboratory environment in Goiânia City, Goiás State, Brazil, and observed that operating air conditioners between 8-6 a.m. provided a water flow of 2.7-4.1 litres in 1 hour, and as a result, an average of 3.08 litres of water was produced in 1 hour. Khan (2023) evaluated the quality and quantity of air conditioning wastewater in a study conducted at the European University of Bangladesh and found that air conditioners with 1 ton, 2 ton and 4 ton power produced 97, 177 and 354 litres of water in a month, respectively. In a study conducted by Alom et al. (2021) evaluating the usability options of air conditioning wastewater, it was found that air conditioners with 3, 4 and 4.5 ton/h power operated for 9 hours a day produced 2.159, 2.997 and 3.101 litres of water during the day, respectively, and air conditioners operated for 5 hours at night produced 1.849, 2.695 and 2.702 litres of water, respectively. In a study conducted by Noutcha et al. (2016) on the ground destruction of air conditioner wastewater, it was recorded that a total of 1,459.5 litres were produced in the first month by operating air conditioners of different brands for 48 hours, and 965.5 litres were produced in the second month by operating them for 36 hours. In a study conducted by Akram et al. (2018) evaluating the physical and chemical properties of air conditioner wastewater, it was recorded that in the climatic conditions of Dhaka City, Bangladesh, a 2 ton air conditioner produced 3.5-4.5 litres of water in 1 hour and 25 litres of water in a day.

In a study conducted by Uddin et al. (2019) evaluating the possible usage areas of air conditioner wastewater, it was observed that 19 air conditioners of different powers and brands produced an average of 1.10 litres of water per ton according to the wastewater production values in the climatic conditions of Gazipur and Dhaka Cities, Bangladesh. Galindo (2019) investigated the possibility of air conditioning wastewater as an alternative water source and observed that a window-type 0.75 hp air conditioner produced 25.92-36.72 litres of wastewater per day. In a study conducted by Okeyinka et al. (2021) on the possibility and quality of air conditioning wastewater use in institutional buildings, it was reported that an average of 15.33 millilitres of water was produced when operated for 8 hours in an environment where the air temperature was 24.9 degrees and the humidity rate was 60.1%, and a total of 7.40 litres of wastewater was produced per day. In a study examining the physical and chemical properties of air conditioning wastewater conducted by Matarneh et al. (2024), it was determined that 1 ton (38 units), 2 ton (40 units) and 3 ton (36 units) air conditioners operated at an average temperature of 18 degrees in June and July 2023 produced 480, 650 and 870 litres of wastewater in a month, respectively. Siam et al. (2019) evaluated the possibility of air conditioning wastewater as a water source in terms of quality and quantity in Palestine, where water shortage is severe. They observed that in Ramallah, air conditioners with 1, 2 and 3 tons of power operated for an average of 6.64 hours per day produced approximately 9.63, 18.46 and 25.1 litres per day, respectively, and an average of 259 litres per month. In Jericho, air conditioners with 1, 2 and 3 tons of power operated for an average of 6.64 hours per day produced approximately 15.40, 36.09 and 43.34 litres per day, respectively, and an average of 453 litres per month.

According to the International Energy Agency (IEA) data, the number of air conditioners in the world, which was approximately 2 billion by 2024, is expected to almost triple by 2050, reaching 5.5 billion (Ritchie, 2024). According to a study conducted by Marketing Türkiye in 2021, the air conditioner usage rate in Türkiye is 21.7%, with the highest air conditioner usage in the Mediterranean (28.8%) and the Aegean (27.1%) regions, while the lowest usage rate was in the Northeastern Anatolia Region (15.7%). According to the report published by the Air Conditioning and Cooling Air Conditioning Manufacturers Association in Türkiye, approximately 1.9 million split air conditioners were sold in 2023 (Dünya Gazetesi. 2024). On a Türkiye scale, based on air conditioner sales in 2023, according to these data, assuming that all 1.9 million split air conditioners have a power of 1 ton, operate for approximately 7 hours per day, and produce approximately 9 litres of water per day (Siam et al., 2019), they can produce a total of 17,100 tons of water per day. When evaluated alone, this value is small, but when combined, its impact is large. Another important issue is whether the water produced by air conditioners meets certain standards for collection and use.

5. Analysis Values of Wastewater Produced by Air Conditioners

According to the working principles of air conditioners, wastewater is produced as a result of the air conditioners collecting water vapour particles in the air due to their instant heating and cooling functions, condensing them and converting them from gaseous to liquid (Snidvongs and Vongsumran, 2020). Like all other wastes generated in production/consumption processes, air conditioner wastewater is a waste produced by air conditioners while they are providing their service in controlling the ambient climate. The effect created by the waste economy, the idea of how to make more use of waste, and more importantly, the need for a vital resource such as water, has brought the wastewater produced by air conditioners to the agenda (Knight, 2023). Water is a vital resource for the continuation of life, but not every water source can be used to meet every water need. In this sense, water resources must meet certain standards in order to meet a specific need such as drinking water and irrigation water (Dinka, 2018).

The possibility of using air conditioning wastewater and its areas of use also depend on the capacity to meet the standards determined in this area. The waste produced by air conditioners can be used as drinking water if it has the characteristics determined by WHO (water does not contain chlorine, sodium, potassium, volatile organic chemicals and inorganic trihalomethanes, microbial pathogens and pesticides).

Table 2. Comparison of heavy metal values in air conditioning wastewater with WHO water standards

Heavy Metals	[1]WHO max (mg L^{-1})	[2]AC (mg L^{-1})	[3]AC (mg L^{-1})	[4]AC (mg L^{-1})	[5]AC (mg L^{-1})	[6]AC (mg L^{-1})	[7]AC (meq L^{-1})
Arsenic As	0.010	<0.010	0.00079	-	-	-	0.0019-0.0048
Antimony Sb	0.005	<0.001	-	-		-	
Lead Pb	0.010	<0.010	0.00051	0.015-0.049	-	-	0.0081-0.0261
Mercury Hg	0.001	<0.001	-	-		-	0.0035-0.0318
Chromium Cr	0.050	<0.010	0.00102	0.001-0.002	0.021-0.19	-	
Cadmium Cd	0.003	<0.001	0.00022	0.001	-	-	0.0008-0.0061
Calcium Ca	-	0.050	-	-		-	
Copper Cu	2.000	0.900	0.00119	0.008-0.061	0.068-1.81	0.23	0.4587-1.4270
Iron Fe	0.300	<0.010	0.062	0.001-0.012	0.032-9.29	0.543	0.1870-1.1427
Zinc Zn	3.000	<0.020	0.00053	0.013-0.325	0.020-0.56	0.18	0.0935-0.4654
Selenium Se	0.010	<0.010	-	-	-	-	
Beryllium Be	-	<0.010	-	-		-	
Magnesium Mg	-	0.030	-			0.59	
Manganese Mn	0.500	<0.010	-	0.005-0.014	0.013-0.19	-	
Barium Ba	0.700	<0.100	-	-	0.033-0.75	-	0.0135-0.1421
Boron Br	0.300	<0.010	-	-		-	
Molybdenum Mo	0.070	<0.010	-	-	-	-	
Nickel Ni	0.020	<0.010	0.00066	0.013-0.096	-	0.171	
Aluminium Al	0.200	<0.010	0.0305	-	0.056-11.50	0.226	

mg L^{-1}= milligrams per litre, µg L^{-1}= micrograms per litre, meq L^{-1}= milliequivalents per litre (to express the concentration of ions in solution), AC= air conditioning. WHO= World Health Organization. [1]WHO, 2019; [2]Snidvongs and Vongsumran, 2020; [3]Matarneh et al., 2024; [4]AlGhamdi et al., 2024 (Values µg L^{-1} were converted to 'mg L^{-1}'); [5]Siam et al., 2019; [6]Glawe et al., 2016; [7]Bautista-Olivas et al., 2017.

Table 2 presents data from different scientific studies that determine the heavy metals in air conditioning wastewater and compare them with the standards determined by WHO.

According to the analysis of air conditioning wastewater by Snidvongs and Vongsumran (2020), it was concluded that the heavy metals that can harm humans in air conditioning wastewater are within the WHO standards and can be used as drinking water (Table 2). Matarneh et al. (2024) reported that the values in water content according to the heavy metal detection test results of air conditioning wastewater are much lower than the maximum limits determined by Jordan and FAO for drinking water and agricultural irrigation water (Table 2). In their study, AlGhamdi et al. (2024) concluded that the content of heavy metals and all other elements in water samples of air conditioning wastewater produced by window and split air conditioners met the standards determined for drinking water and irrigation and were within acceptable thresholds (Table 2). Siam et al. (2019) reported that according to the heavy metal detection test results of a total of 59 samples of water, the heavy metals lead, cadmium, arsenic, selenium, tin, molybdenum, nickel, cobalt and lithium were not found in the air conditioning wastewater content; some samples contained copper, iron, aluminium, chromium, barium, zinc and manganese; in some samples, the values of iron, aluminium, chromium, barium and zinc were below the acceptable limits within the drinking water standards (Tablo 2).

Glawe et al. (2016) compared the analysis results of wastewater samples taken from 19 central air conditioning systems with more than 5.42 ton in San Antonio, USA, with the standards in the National Primary Drinking Water Regulations and concluded that the quality of air conditioning wastewater is relatively high; heavy metal content is low, microbial content has the potential to increase depending on temperature; and it needs to undergo a series of processes for use for certain purposes (Table 2). Bautista-Olivas et al. (2017) observed that the content of heavy metals in water obtained by condensing atmospheric water vapour in day/night, humid/dry weather conditions in three cities of Mexico (Tlaxcala, Hidalgo and Mexico City) was above WHO standards with Pb (91.66%), Fe (58.33%) and Cd (33%) values, respectively, and the remaining heavy metals were within WHO standards (Table 2).

Table 3 presents data from different scientific studies comparing the water quality of air conditioning wastewater with the standards set by WHO.

Table 3. Comparison of air conditioning wastewater quality values with WHO water standards

Water Quality Characteristics	[1]WHO max	[2]AC	[3]AC	[4]AC	[5]AC	[6]AC	[7]AC	[8]AC
Colour (Pt-Co)	15	<5	-	0.42-0.83	-	Colorless	32	-
Turbidity (NTU)	5	<1	1.12	078-0.42	-	0.69-1.66	1.57	5
pH (Acidity/Alkanity)	-	6.6	7.20	0.86-0.10	6.94-7.03	6.50-8.50	7.26	7.07-7.35
Conductivity (µ.m cm^{-1})	-	21	82	0.96-0.09	15-108.5	-	75.5	20.30-29.16
Taste (Tongue)	OK	OK	-	-	-	-	-	-
Odour (Smelling)	OK	OK	-	-	-	Odorless	-	-
TDS (mg L^{-1})	1000	1	41.15		12-91	190-240	-	11.90-22.09
Total Alkalinity (mg L^{-1})	-	<1		093-0.08	-	40-45	-	12-17
Total hardness (mg L^{-1})	-	<1	34.51	0.71-0.41	1-18	-	-	10.12-15.44
Nitrate nitrogen	11.3	<0.01	12.80	-	-	-	-	13.20-18.32
Fluoride (mg L^{-1})	1.5	0.3	-	-	-	-	-	-
Chloride (mg L^{-1})	250	1	-	-	-	26.63-35.50	-	10.85-16.44
Sulphate (mg L^{-1})	250	1.7	-	-	-	-	-	-
Sodium (mg L^{-1})	-	0.2	-	-	-	-	-	-
Phosphate (mg L^{-1})	-	<0.01	-	-	-	-	-	3.39-5.62
Silica (mg L^{-1})	-	0.04	-	-	-	-	-	-
Total PCA (cfu mL^{-1})	-	110	-	-	-	-	-	-
Coliforms (cfu 100 mL^{-1})	-	0	-	-	0	-	160	$1.5\text{-}4.4\times10^3$
TTHM (100 µg L^{-1})	-	<0.005	-	-	-	-	-	-

Pt-Co= platinum-cobalt, NTU= nephelometric turbidity unit, AC= air conditioning, TDS= total dissolved solids PCA= plate count agar, CFU= colony forming units, TTHM= total trihalomethanes, WHO= world health organization. [1]WHO, 2019; [2]Snidvongs and Vongsumran, 2020; [3]Matarneh et al., 2024; [4] Scalize et al., 2018; [5]Sabnis et al., 2020; [6]Khan, 2023; [7]Alom et al., 2021; [8]Noutcha et al., 2016.

Snidvongs and Vongsumran (2020) concluded that the quality characteristics of air conditioning wastewater are better than WHO standards and can be used as drinking water as a result of their analysis of air conditioning wastewater (Table 3). AlGhamdi et al. (2024) observed that the water quality characteristics of air conditioning wastewater (pH, total dissolved solids, electrical conductivity, dissolved and chemical oxygen values, phosphate, chlorine, sulphate) meet the standards set for drinking water and irrigation, and that split air conditioners produce more air conditioning wastewater than window-type air conditioners and are better in terms of water quality (Table 3). Siam et al. (2019) reported that according to the physical, chemical and microbial analysis results of air conditioning wastewater, the pH value is at a neutral level, the total dissolved solids, electrical conductivity and dissolved oxygen values are within the standards of the State of Palestine; in terms of other characteristics, the water quality of air conditioning wastewater is of good quality in accordance with irrigation water standards, but it is controversial because the biological and chemical oxygen demand measurement values do not meet the drinking water standards.

According to the results of the physicochemical and bacteriological analysis of air conditioning wastewater, Scalize et al. (2018) determined that the water quality of air conditioning wastewater is in the range of distilled water, more like pure water, and that it has the potential to be used in Water Analysis Laboratory activities (Table 3). Matarneh et al. (2024) compared the quality characteristics of air conditioning wastewater and found that pH was at neutral level, total dissolved solids, electrical conductivity, biochemical oxygen demand, and hardness levels met Jordanian and FAO drinking water standards (Table 3). According to these results, Matarneh et al. (2024) test results of air conditioning wastewater samples show that it meets the standards and safety requirements determined by the State of Jordan and the FAO in terms of drinking water and irrigation water. Sabnis et al. (2020) concluded that according to the results of the physicochemical and bacteriological analysis of air conditioning wastewater, no Echolium was found in all water samples, the water quality of the air conditioning wastewater was at a neutral pH level and in terms of other properties, the air conditioning wastewater was suitable for domestic and industrial use. According to the results of the physical, chemical and bacteriological analysis of air conditioning wastewater, Khan (2023) found that air conditioning wastewater generally met the quality standards determined by the Bangladesh Government for drinking water and domestic use. According to the physical, chemical and bacteriological analysis results of air conditioning wastewater conducted by Alom et al. (2021), the waste air conditioning water does not meet the drinking water standards of Bangladesh because it contains a large number of E coli and a high level of BOD, but according to the test results in the laboratory, they reported that this water is suitable for drinking water after filtering and boiling on air conditioning wastewater. Noutcha et al. (2016) found that the physicochemical properties of the air conditioning wastewater were generally within the limits determined by the WHO, while the microbial values did not meet the quality standards determined for drinking water use, and therefore these waters could be used for cleaning purposes in a laboratory environment.

Akram et al. (2018) reported that according to the results of the physical-chemical and bacteriological analysis of air conditioning wastewater, the water quality of air conditioning wastewater is very close to the quality of distilled water and can be used like pure water. Uddin et al. (2019) concluded that the analysis results of air conditioning wastewater meet the Bangladesh Government water standards and the standards set by WHO in terms of water quality drinking water and that this water can be used for drinking, washing and other domestic purposes, irrigation and fishing purposes. Okeyinka et al. (2021) concluded that the analysis results of air conditioning wastewater did not meet the water quality drinking water standards, but it was of sufficient quality for domestic use and in the amount determined by WHO for individual use.

In general, the quantity and quality characteristics of air conditioning wastewater vary depending on factors such as the climate characteristics of the environment, the power of the air conditioner, and the water collection and storage system (Scalize et al. 2018).

6. Possible Usage Areas of Air Conditioning Wastewater

Sustainability and sustainable economic activities have emerged from the necessity to make new production/consumption processes dominant in economic, social and environmental areas in order to minimize or eliminate the effects of risks (such as climate change, acid rain, loss of biodiversity, pollution of air, water and soil resources) that threaten the existence of nature, humans and other living beings, resulting from the excessive consumption of nature (production factors, living space) used to meet human needs. In this respect, the correct management, destruction, preservation and evaluation of wastes resulting from various production/consumption processes that cause great harm to nature and their recycling into the economy and the relieving of the burden of these wastes on nature are essential for the continuation of human existence. The waste economy, expressed with the concept of circular economy, processes these wastes with developing technology, adds economic value and produces solutions to many problems, especially environmental pollution costs, by transforming them into inputs that replace the scarce resources required for production. At this point, the advantage of processing waste is that it has lower production costs than other resources, and also saves the need to incur a considerable cost to manage these wastes, making the waste economy very valuable.

Water, which constitutes 75% of the world (ATO, 2023) and the human body (SUDER, 2024) and is the source of life in both, is a very valuable resource and according to projections, the amount of water needed for human life is decreasing (WWF, 2023). In this sense, the possibilities of evaluating every drop of water should be calculated. Air conditioning wastewater is produced by air conditioners without any production cost, under suitable conditions; a 1 ton air conditioner produces 1.10 litres of water per hour; (Uddin et al., 2019). A significant amount (there are 2 billion air conditioners in the world; Ritchie, 2024) is produced without any cost and is thrown away without being evaluated. In addition to the negative environmental and social effects, the economic loss experienced is incredible. Scientific research conducted on the evaluation of air conditioning wastewater within the scope of waste economy provides scientific evidence that air conditioning wastewater can be an alternative solution to water scarcity. Accordingly, in these studies: Studies by Snidvongs and Vongsumran (2020), Khan (2023), AlGhamdi et al. (2024), and Matarneh et al. (2024) reported that air conditioning wastewater is a suitable source for irrigation and domestic use, including drinking water. Uddin et al. (2019) expressed a wider scope for the use of air conditioning wastewater and reported that air conditioning wastewater can be used for drinking, washing and other domestic purposes, irrigation and fishing purposes. Sabnis et al. (2020) reported that air conditioning wastewater can be collected with a simple arrangement and used for both domestic and industrial purposes, while Noutcha et al. (2016) and Scalize et al. (2018) reported that air conditioning wastewater can be used for cleaning purposes in Laboratory activities. A similar finding was reached in the study conducted by Galindo (2019), who concluded that air conditioning wastewater could be considered as a potential alternative water source other than drinking water use. In the study conducted by Okeyinka et al. (2021), according to the results of the physico-chemical analysis of air conditioning wastewater, they concluded that air conditioning wastewater has an acidic structure and this acidic structure can be neutralized with pH correction processes and become suitable for domestic use. Okeyinka et al. (2021) concluded that air conditioning wastewater can be used for domestic purposes, Akram et al. (2018) in pure water usage areas, and Siam et al. (2019) as irrigation water.

Abdullah and Mursalin (2021) reported in their study that a 2-ton air conditioner produces an average of 25 litres of wastewater per day, and that this air conditioner wastewater can be used in various applications including vehicle batteries, radiator water, toilet flushing, industrial purposes, laundry, aquarium fish culture and irrigation. In a study conducted by Elveren et al. (2018), while the crop productivity decreased in wheat and barley production grown with irrigation water mixed with air conditioning wastewater at different rates, the negative result was that the products decreased and toxic substances accumulated in the product, Siam et al. (2019) concluded that it can be used as irrigation water. In a case study conducted by Bastos and Calmon (2013) to reduce water costs in a workplace, It was found that the air conditioners in a workplace produced 4.8 litres of water per hour, which corresponds to a significant amount of water used in the toilets in the workplace, and that 5,530 litres of this water was used by 820 employees to clean the toilets, of which 4,298.10 litres was produced by air conditioners, and it was expected that an economic gain of 77.72% would be achieved.

7. Conclusion

The continuation of human existence depends on sustainable economic activities, sustainable economic activities depend on effective and efficient resource use, effective and efficient resource use depends on using each resource while preserving its ability to renew itself, and the ability of each resource to renew itself depends on the correct disposal, preservation and evaluation of wastes resulting from various production/consumption processes and their reintroduction into the economy. In the world, 2.1 billion tons of waste is produced with a management cost of 495 billion dollars and a very small portion of this waste, 400 million tons, is recycled to the economy, providing 130 billion dollars of income. Especially 80% of the 6.8 billion tons of plastic waste that is suitable for recycling, 83% of the 56.3 million tons of electronic waste and 81% of the 935 billion tons of organic waste are thrown into nature. When the situation is evaluated in terms of water source, which is a very valuable resource, tons of waste water produced by approximately 2 billion air conditioners in the world at zero cost (a 1 ton air conditioner can produce 1.10 litres of water per hour) is wasted while it could meet many water needs. Scientific studies on the subject provide evidence supporting that air conditioning wastewater can be an alternative water source. The amount of air conditioning wastewater production depends on the power of the air conditioner, the climate characteristics of the environment and the operating time of the air conditioner. There are scientific studies that conclude that the wastewater values produced by air conditioners are in compliance with the WHO drinking water standards. There are also scientific studies that conclude that the particles in the working environment of air conditioners do not meet the WHO standards due to the high content of heavy metals (such as copper, iron, aluminium, chromium, barium, zinc and manganese) and the high content and density of microbial pathogens and pesticides harmful to humans. However, in general, most studies provide evidence supporting that these wastewaters can be used for different purposes and needs such as drinking, irrigation, domestic and industrial use and that significant economic gains will be achieved. The study results provide strong evidence that significant economic values will be gained from both the environmental costs incurred due to these wastes and the production costs by obtaining the raw materials required for production by managing wastes correctly. More scientific studies should be conducted on wastes, which are a very sensitive issue, and effective waste management should be provided all over the world by sharing knowledge and experience.

Author Contributions

The percentages of the author contributions are presented below. The author reviewed and approved the final version of the manuscript.

	H.S.
C	100
D	100
S	100
L	100
W	100
CR	100
SR	100

C=Concept, D= design, S= supervision, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The author declared that there is no conflict of interest.

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