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Integration of renewable energy in wastewater treatment during COVID-19 pandemic: Challenges, opportunities, and progressive research trends

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ABSTRACT

SARS-CoV-2 has aroused drastic effects on the global economy and public health. In response to this, personal protective equipment, hand hygiene, and social distancing have been considered the most important ways to prevent the direct spread of the virus. SARS-CoV-2 would be possible survive in wastewater for a few days, leading to secondary transmission via contact with water and wastewater. Thus, the most economical and practical approaches for decentralized wastewater treatment are renewable energies such as the solar energy disinfestation process. However, as freshwater requirements increase and fossil fuels become unsustainable, renewable energy becomes more attractive for desalination applications. Solar photovoltaic, membrane-based, and electricity desalination technologies are becoming increasingly popular due to their lower energy requirements. Several aquatic environments could be benefitted from solar energy wastewater disinfection. Besides, utilizing solar energy during the day can inactivate SARS-CoV-2 to nearly 90%. However, conventional membrane-based desalination practices have also been integrated, including reverse osmosis (RO) and electrodialysis (ED). Several exciting membrane processes have been developed recently, including membrane distillation (MD), pressure-reduced osmosis (PRO), and reverse electrodialysis (RED). Such operations can produce clean and sustainable electricity from brine and impaired water, generally considered hazardous to the environment. As a result, neither PRO nor RED can produce electricity without mixing a high salinity solution (such as seawater or brine and wastewater, respectively) with a low salinity solution. Herein, we critically review the progress in applying renewable energy such as solar energy and geothermal energy for generating electricity from wastewater treatment and uniquely discuss the effects of these two types of renewable energy on SARS-CoV-2 in air and wastewater treatment. We also highlight the significant process made on the membrane processes utilizing renewable energy and research gaps from the standpoint of producing clean and sustainable energy. The significant points of this review are: (1) among various types of renewable energy, solar energy and geothermal energy have been predominantly studied for wastewater treatment, (2) effects of these two types of renewable energy on SARS-CoV-2 in air and wastewater treatment are critically analyzed, and (3) the knowledge gaps and anticipated future research outlook have been consequently proposed thereof.

1. Introduction

Several contaminants are common in wastewater systems, including urine and faeces (Table 1) (Foladori et al. 2020). Various pathways can lead to SARS-COV-2 RNA (Figs. 1 and 2) getting into wastewater systems, emphasizing the virus's potential transmission path (Ahmed et al., 2021). For example, hospitals and isolation centres can discharge wastewater containing SARS-COV-2 (Zhang et al., 2020). A recent study reported that approximately 67% of stool samples from infected people were tested positive for SARS-COV-2 RNA. Also noted is that SARS-COV-2 RNA may still be detected in stool even after the respiratory infection has resolved; respiratory samples are

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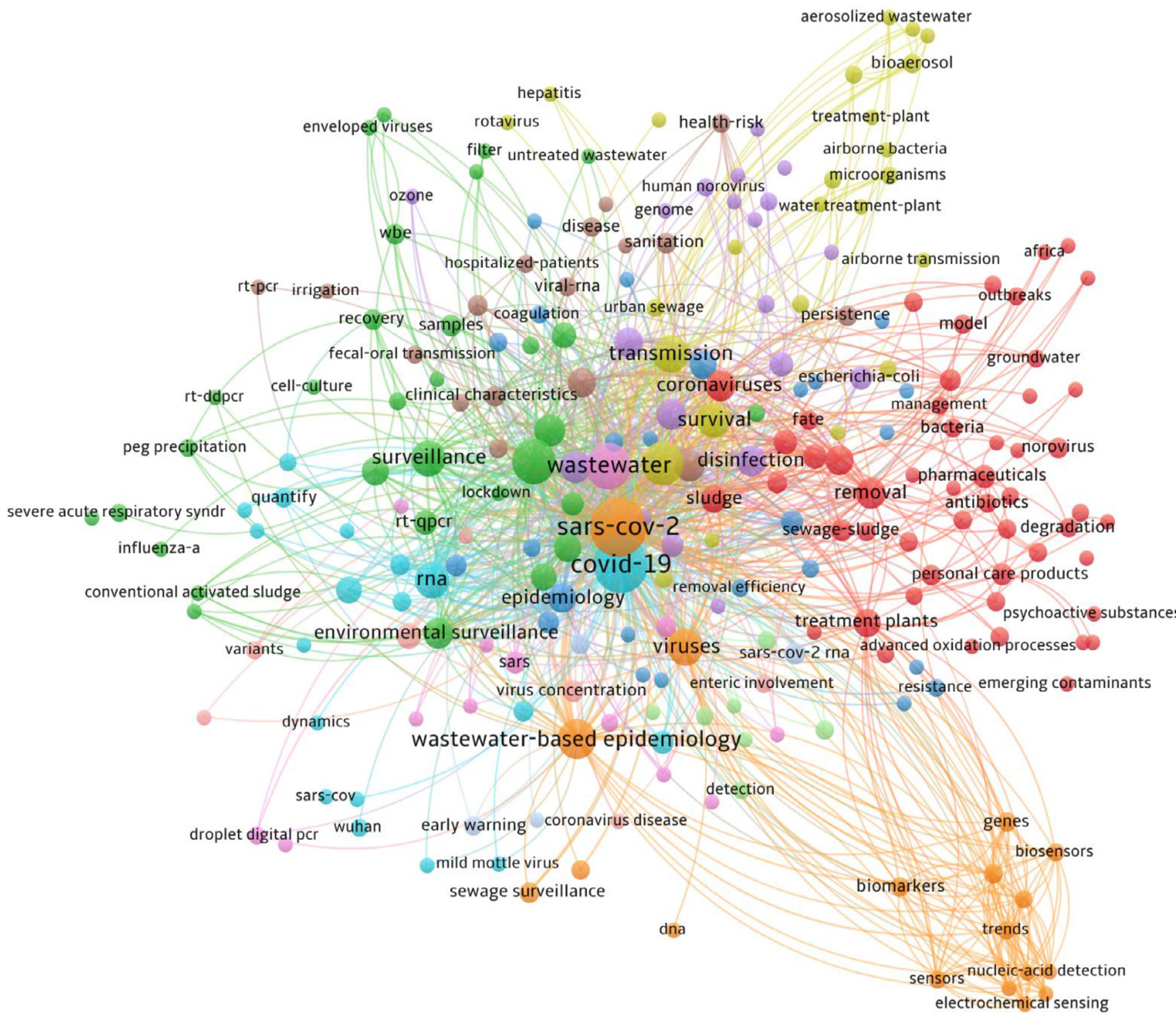
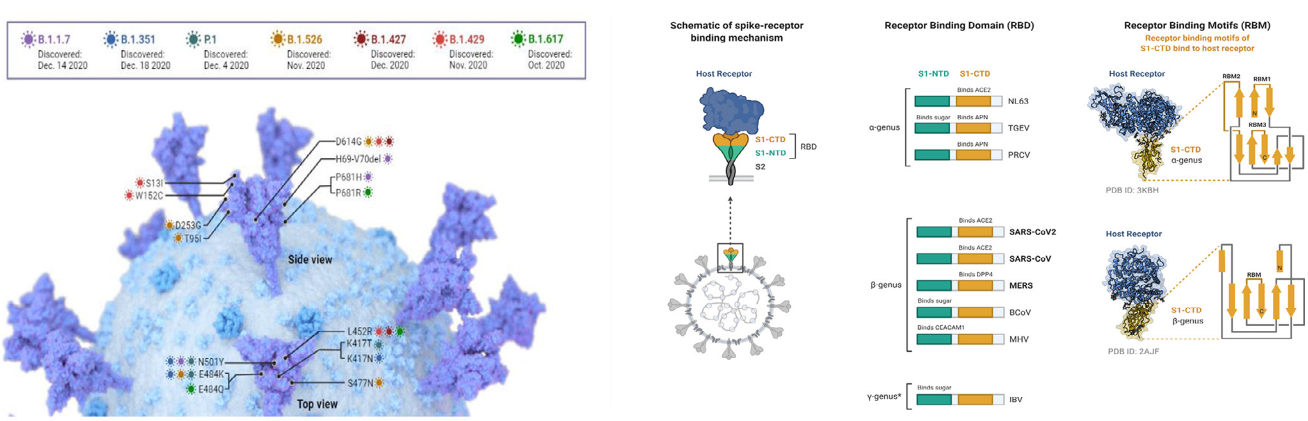


Fig. 1. Network visualization of terms associated with wastewater treatment and SARS-CoV-2.



(a) (b)

Fig. 2. (a) Key mutation in the spike protein (b) Mechanism of coronavirus.

Table 1
The detection of infectious SARS-CoV-2 in human feces and diarrhoea.

SARS-CoV-2 found in human feces (%)	People diagnosed with diarrhea (%)	Key results	Refs.
29	-	In the stool samples from two patients without diarrhea, there was evidence of live SARS-CoV-2.	(Wang et al., 2020)
47.7	24.2	Despite having positive feces and GI symptoms in 22/42 (52.4%), there were no GI symptoms in 9/23 (39.1%), though positive feces were present.	(Lin et al., 2020)
53.4	-	Positive stool results occurred from 1 to 12 days after patients were negative in respiratory tests - 23.3% of patients were positive in stool tests after their respiratory test was negative.	(Xiao et al., 2020)
80	30	There are only three symptoms of diarrhea, and no other gastrointestinal symptoms reported	(Xu et al., 2020)
55	-	Positive fecal samples did not seem to be associated with GI symptoms; Positive feces persisted for an average of 11.2 days after negative respiratory samples.	(Wu et al., 2020)
15.3	22	Positive fecal and urine sample.	(Cheung et al., 2020)
48.1	12.5	Even after negative respiratory samples were taken, virus RNA was still found in stool.	(Cheung et al., 2020)

negative (Jones et al., 2020). Moreover, according to the Luo study, the gastrointestinal tract can replicate viruses (Luo et al., 2021). As a result, contaminated wastewater may contain significant infectious viruses (Crank et al., 2022). In addition, in low-income countries, wastewater can spread SARS-COV-2 if discharged directly into surface waters without proper treatment. Due to this, groundwater resources are not safe because they could also be contaminated with viruses from recharged groundwater (Peccia et al., 2020, Randazzo et al., 2020).

Increasing population and industrial development drive global energy demand to an all-time high. Over the past two generations, there have been significant increases in population, especially in developing countries (Flow chart 1). A significant challenge of the 21st century is avoiding energy crises (Brosemer et al., 2020, Rosa et al., 2021). Due to a growing population, energy demand is increasing rapidly. In order to establish themselves in the world, different countries have different strategies, plans, policies, and control measures. The global population is growing, and resources are depleted (Qazi et al., 2019). Therefore, consideration of energy sources plays a crucial role in satisfying the world's needs and population (Shahsavari et al., 2018). Many factors affect the energy level available to people, including a country's development profile (Neofytou et al., 2020), economic status (Mofijur et al., 2021), and technological advancements within the nation (Sütterlin et al., 2017). Effects on the ecosystem have been substantial due to the emission of various gases caused by the burning of fossil fuels, which are readily available and are frequently used to satisfy the world's energy demands (Yoshida et al., 2019).

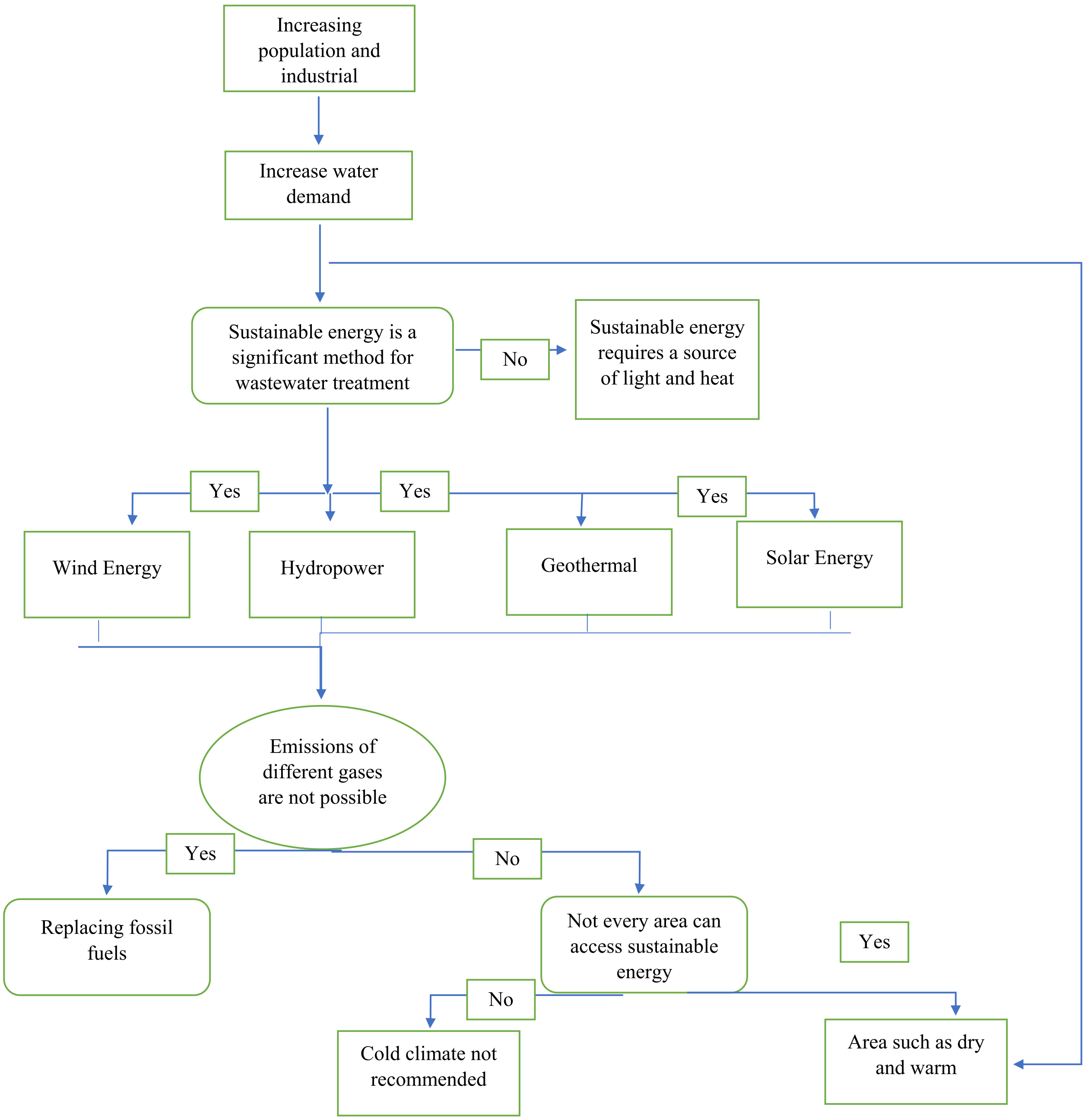
It is clear from the geographical location of ancient civilizations and cities that freshwater sources have been critical to the growth of civilization since ancient times (Manuel et al., 2018). Water consumption has increased massively in the past few decades due mainly to improved living standards, increased population, and a highly industrialized economy (Xie et al., 2018). Thus, the lack of fresh water has become a severe concern for many countries around the world. Also, there is a strong correlation between the amount and the development of civilization in water-stressed areas (Kummu et al., 2011). According to UN-Water, more than half of the world's population will have no access to clean drinking water by 2025 (Almost one out of every ten people live without access to essential drinking water, and approximately 771 million people are without safe drinking water). In spite of the fact that water covers 75% of the earth's surface, the majority of the water contained in reservoirs cannot be used directly (Tortajada et al., 2018). Most fresh water in the world comes from conventional sources, such as rivers (Jackson et al., 2013), lakes (Sinang et al., 2015), and groundwater (Gude 2018). Therefore, drinking water, however, is primarily found in groundwater. Furthermore, freshwater resources in different parts of the world are not distributed proportionally to the population and water usage. There is no doubt that these statistics support the idea of obtaining portable water from non-conventional sources, such as the sea, rivers, and lakes located in water-stressed areas (Rozemeijer et al., 2021).

Currently, replacing fossil fuels with sustainable energy is high on the international political agenda for climate protection due to the energy turn (Kåberger 2018). This issue is addressed by several European initiatives and strategies that will help shape the energy industry's future (Jensen et al., 2018). A temperature rises of 2°C or less is the goal of the 2020 Sustainable Development Goals. There now are three additional targets added to the 2030 climate & energy framework: a minimum 40% reduction in greenhouse gas emissions and 27% renewable energy usage by 2030 and improvement in energy efficiency by 27% (Knopf et al., 2015). Research into low-carbon technologies and their development is established in the Strategic Energy Technology Plan. Globally, Sustainable Development Goals focus, among other things, on ensuring everyone has access to energy that is affordable, reliable, sustainable, and modern (Fig. 3) (Amesho 2019). Since it is regarded as a resource accessible to every household without interruption, wastewater attracts attention in this context (Kollmann et al., 2017).

Nevertheless, Solar energy (Pandey et al., 2021a,b), wind energy (Shoaib et al., 2019), hydropower (Kougias et al., 2019), and geothermal (Bayer et al., 2019) are all eco-friendly energy sources (Fig. 4). For many reasons, solar energy may prove to be the best choice for the future: The first demonstration of solar energy's abundance is that the sun emits about 3.8 1023 kW of solar energy daily, out of which the earth intercepts about 1.8 1014 kW. Besides light and heat, solar energy is received by the Earth in different forms. The bulk of this energy is absorbed, scattered, and reflected by clouds as it travels. Several studies revealed that solar energy could fulfill most of the world's energy needs because it is abundant in nature and free to use. As a second reason for its promise, it is a source of energy that can be used indefinitely with stable and progressively higher output efficiencies than any alternative energy source (Fig. 5) (Elsheikh et al., 2019).

However, wastewater treatment plants (WWTPs) are primarily designed to remove undissolved and dissolved matters from wastewater (cooking fats, oils, road grit, and nutrients) (Tian et al., 2021). In this way, WWTPs play a crucial role in the control of water pollution as well as sanitary engineering. Increasingly, wastewater professionals are becoming interested in the additional energy generation potential of WWTPs beyond that of on-site digester gas combustion or cogeneration (Capodaglio et al., 2020). The concept of wastewater as an energy source must be reconsidered, such as utilizing digested sewage sludge for incineration and electricity generation can provide a significant amount of energy recovery (Wang et al., 2021). Furthermore, on-site energy generation at WWTPs could allow nutrient recycling from wastewater and reuse of treated wastewater for irrigation and industrial processes (Marangon et al., 2020). Thus, wastewater-related research focuses on wastewater treatment plants operating as control components in energy distribution systems, wastewater treatment plants utilized as energy storage systems, and metallurgical phosphorus recycling to turn wastewater sludge into energy, fertilizer, and iron (Cudjoe et al., 2020).

Although recent research initiatives and publications related to WWTPs have made significant contributions in energy generation from



Flow chart 1. With the increasing demand for water, sustainable energy demand is essential to the sewage treatment process.

wastewater, the research could focus more on electrical optimization and self-sufficiency (Yan et al., 2020)). The issue of thermal energy seems to be playing only a minor role (Yang et al., 2017). It is estimated that Austrian WWTPs using anaerobic digestion may reach high levels of electric self-sufficiency with optimal wastewater treatment and cogeneration (Gandiglio et al., 2017). On the other hand, WWTPs using anaerobic digestion have lower chances of achieving thermal self-sufficiency than biogas combustion and heat recovery (Duarte et al., 2018). Technologically, there are three primary approaches for generating or recovering heat at wastewater treatment plants: (a) combustion of digester gas via cogeneration, application of in-sewer heat exchangers (Nourin et al., 2021), (b) external heat pumps for wastewater heat recovery (Reiners et al., 2021), and (c) use of solar thermal generation (Verma et al., 2019). In addition to sewage sludge incineration, heat can also be generated (Tarpani et al., 2018). However, in recent decades, impressive technological advancements have led to the introduction of new chemicals, materials, and processes involving a variety of complexities, leading to increased releases of pollutants into the environment, resulting in a requirement for the efficient removal of these pollutants (Levine et al., 2004). Besides, numerous studies have been conducted on various aspects of wastewater treatment technologies, concluding that various techniques have been developed to remove pollutants as well as treat them (Sonune et al., 2004). Sedimentation (Song et al., 2000), flotation (Rubio et al., 2002), filtration (Hube et al., 2020), coagulation (Lee et al., 2012), and flocculation (Lee et al., 2014) are conventional methods of removing solid particles from wastewater. Advanced oxidation processes ((Miklos et al., 2018)), adsorption (Zahmatkesh et al., 2020), and membrane processes (Asif et al., 2021) are more appropriate for removing organic and inorganic compounds from biological treatment than conventional treatment. Despite the effectiveness of water

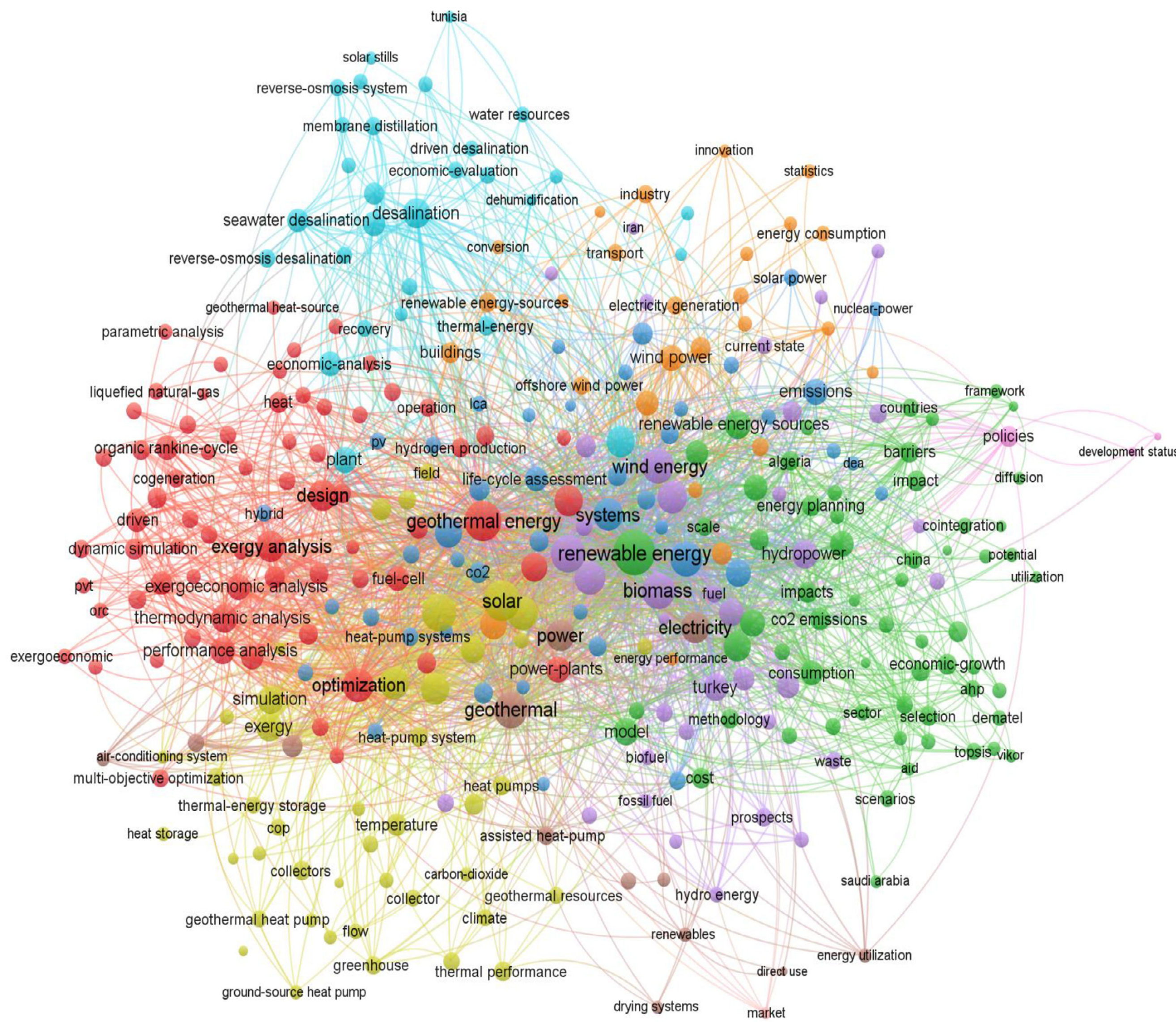


Fig. 3. An increase in the use of sustainable energy in wastewater treatment around the world.

treatment methods used today, they have some drawbacks, such as those that require high levels of energy, cause fouling, and generate many byproducts.

Furthermore, using electrochemical methods in water treatment has advanced to new levels. Electrochemical treatment is characterized by a high removal efficiency, clean energy conversion, pollution avoidance because no emissions are generated, and straightforward operation (Guo et al., 2022). Several electrochemical processes are discussed, including electro-coagulation (Kumari et al., 2021), electro-flotation (Akarsu et al., 2021), electro-oxidation (Guo et al., 2022), electro-disinfection (Rivas et al., 2019), and electro-reduction (Koparal et al., 2002). The electro-coagulation process occurs when metal ions are released into a solution by an anode made of aluminum or iron. According to much research, the use of the alkaline solution in the removal of chemical oxygen demand (COD) is preferable to a neutral or weak acidic solution in aluminum anodes (Wang et al., 2013, Liao et al., 2014). In addition to its advantages, electrocoagulation generates reactive coagulant in-situ and features compact equipment setup (Butler et al., 2011). There are many ways to use electroflotation, such as recovering fine mineral particles, de-inking recycled paper, and separating oil from water (Wang et al., 2009). Anodic oxidation can be classified into direct and indirect (Panizza et al., 2006). The hydroxyl radicals (·OH) or active oxygen (MOx+1) absorbed by the anode surface directly oxidize pollutants in the direct electrooxidation (Linares-Hernández et al., 2010). The process of indirect anodic oxidation commonly uses chlorine, hypochlorite, Fenton's reagent, peroxodisulphate, and ozone as oxidizing agents (Martinez-Huitle et al., 2006). Electro-reduction is also categorized into direct and indirect reduction, as with electrooxidation (Yao et al., 2019). Nitrogen gas is formed from reacting electrons from the cathode surface with nitrate compound, while hydroxyl ions are formed as a byproduct. It is known as a direct reduction process. Electro-reduction is commonly used to treat dye vat wastewater (Roessler et al., 2003, Yao et al., 2019).

By converting membranes into a renewable energy source, desalination can be made more environmentally friendly and sustainable. Membrane operations focus primarily on reverse osmosis (RO) and electrodialysis (ED) as renewable desalination methods. Despite this, some exciting membrane processes emerge with a potentially significant impact on desalination. In addition to membrane distillation (MD) and forward osmosis (FO), there are new processes called renewable energy desalination (RED) and Pressure Retarded Osmosis (PRO). Using these methods can harness/ produce renewable energy and solve issues associated with conventional desalination (Ali et al., 2018).

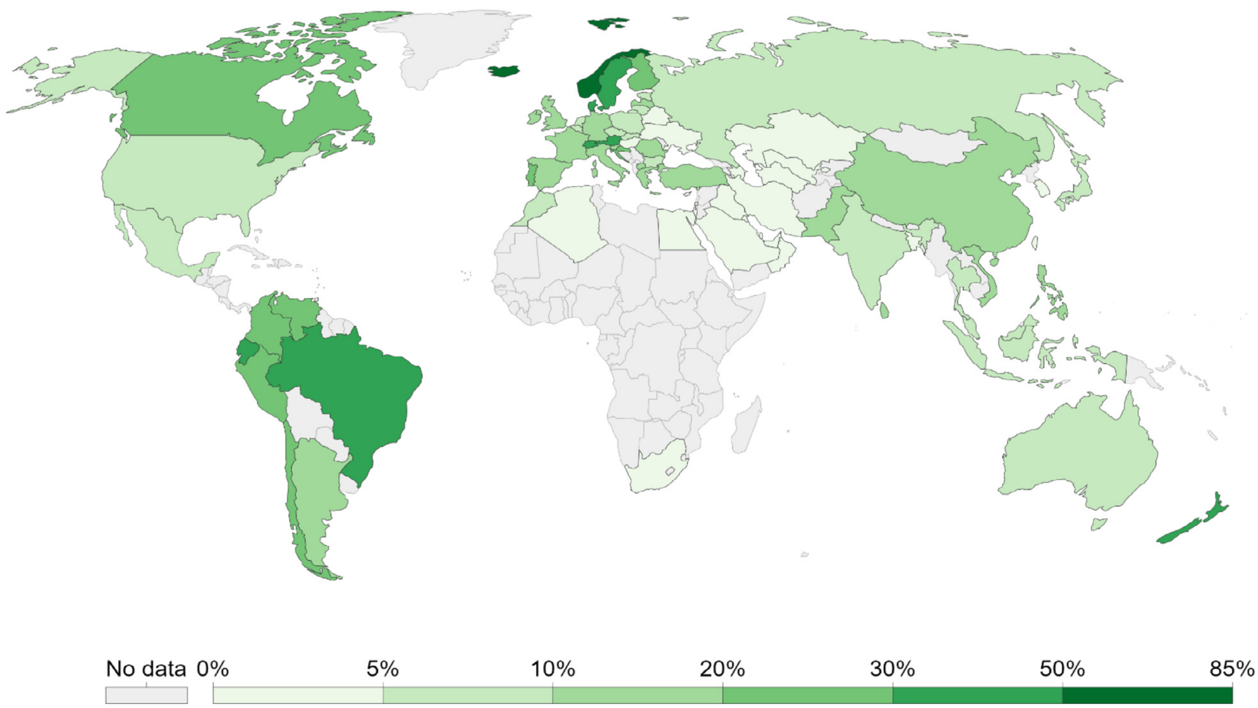


Fig. 4. Network visualization of terms associated with renewable energy.

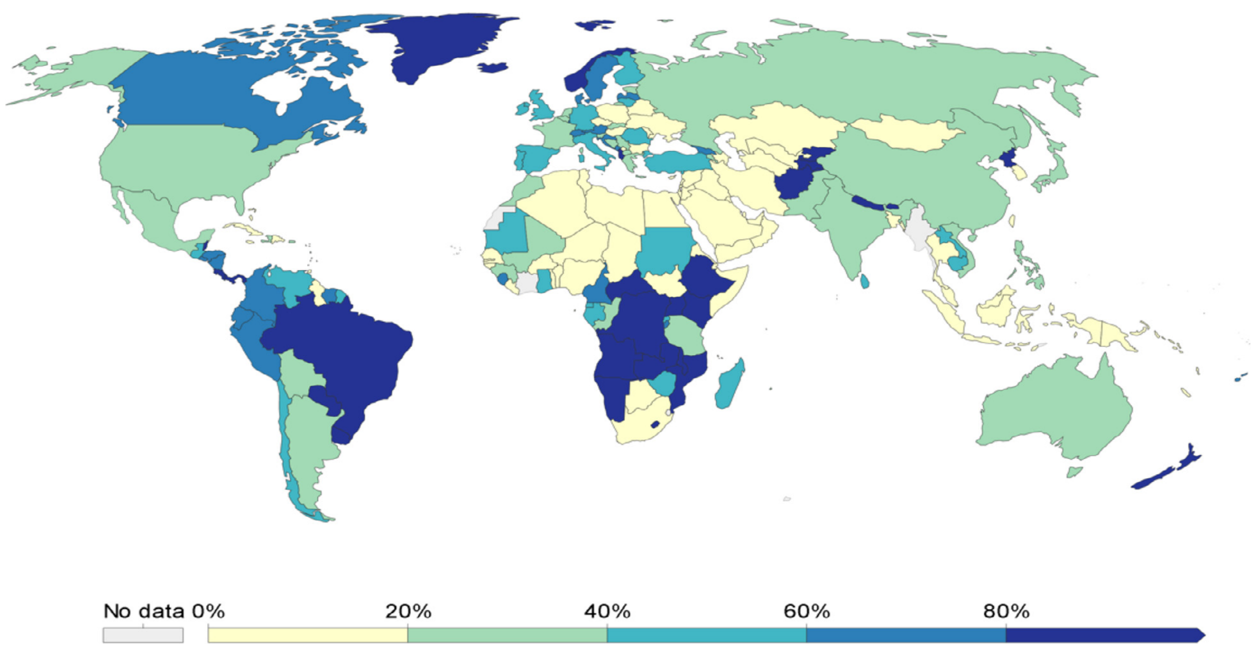


Fig. 5. Electricity produced from renewable sources worldwide by 2020. Renewable energy sources include hydropower, solar energy, wind energy, biomass. Other sources include geothermal, wave, tidal, and waste.

The purpose of this article is to review the aforementioned promising approach of using renewable energy to generate electricity in wastewater treatment as well as the critical technology during SARS-CoV-2. Furthermore, describe the effect of solar and geothermal energy on wastewater treatment during SARS-CoV-2. finally, challenges to and future needs in the use of solar energy for treating wastewater containing SARS-CoV-2

1.1. Routes of SARS-CoV-2 RNA in the aquatic systems

Several channels for transmission of SARS-CoV-1 are identified in apartment buildings with wastewater plumbing systems. SARS-CoV-2 can be transmitted through aerosols or drops of water, much like the SARS-CoV-1 virus (Gormley et al., 2017). It has been reported that the SARS-CoV-1 and SARS-CoV-2 viruses have similar stability in aerosols and on surfaces (Leung et al., 2020). It is possible to remain infectious for several days on surfaces as well as in aerosols if the inoculum is shed (Van Doremalen et al., 2020). Similarly, Ong et al., (2020) investigated SARS-CoV-2 survival in air, surfaces, and personal protective equipment of healthcare workers and disease carriers (Ong et al., 2020). SARS-CoV-2 can be transmitted by stool samples obtained from air outlet fans, door handles, sinks, and toilet bowls, which proves that SARS-CoV-2 can be spread through stools. The following percentage of samples that tested positive for SARS-CoV-2 were collected by Hu et al., (2020) from

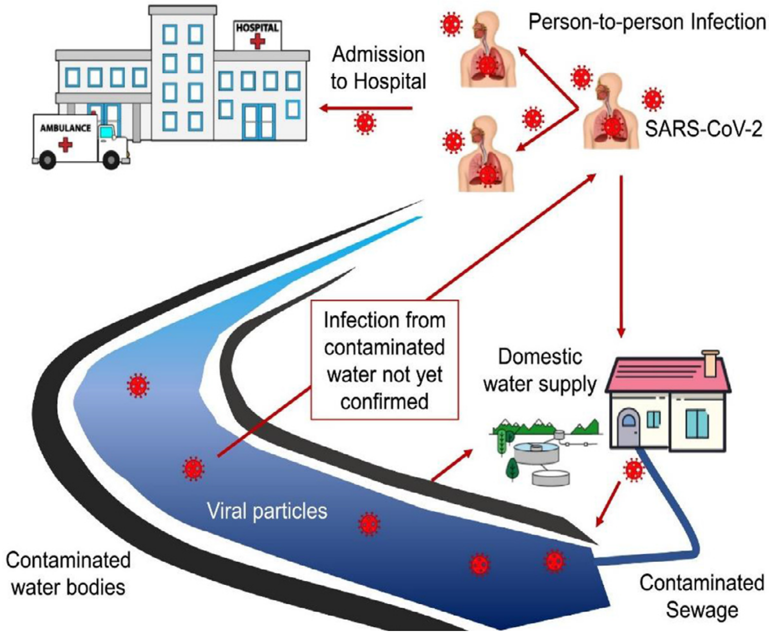


Fig. 6. Sources and routes of SARS-CoV-2 in aquatic systems (Adelodun et al., 2020).

23 high-touch surfaces of a quarantine room: 70% (in the bedroom), > 50% (in the bathroom), > 33% (in the corridor) (Hu et al., 2020). In addition, the toilet bowl and the sewer inlet were among the areas with the highest levels of viral contamination in the room. As a result of this transmission pathway, the sanitary plumbing (or wastewater) system may be responsible for contaminating the surrounding environment and spreading the COVID-19 virus to the nearby cities. Accordingly, Gormley et al., (2020) provided recommendations recently to minimize the transmission of pollutants through the wastewater plumbing system. Fig. 2 summarizes some valuable suggestions to avoid the risk of spreading the pathogen through the wastewater plumbing system in the buildings (Gormley et al., 2020).

Diverse ways are available for SARS-CoV-2 RNA to spread through aquatic environments (Fig. 6), which may lead to the transmission of COVID-19 (Adelodun et al., 2020, Carducci et al., 2020) These routes consist of wastewater from hospitals, isolation wards, and quarantine stations (Wang et al., 2020). It has been confirmed that the discharged contamination is transmitted via contamination of water bodies (Prüss-Ustün et al., 2019). Hence, water sources can become polluted in several different types of ways. Surface waters (streams and lakes) where wastewater is frequently discharged directly without appropriate treatment could be a prospective vehicle for SARS-CoV-2 to spread via waterways to different parts of communities that depend on these water sources for low-income nations daily requirements.

Furthermore, groundwater sources could also become contaminated with disease-causing viruses during the replenishment process because they could be replenished with contaminated water. Hospital waste can also cause disease transmission if disposed of into aquatic bodies without appropriate treatment (Adelodun et al., 2020) underlined a number of studies in which peppermint virus and surface and groundwater have been reported to contain other human enteric viruses-protecting routes through the aquatic system to prevent SARS-CoV-2 and other pathogens from unintentionally reaching these water sources. There is a higher risk of spreading these viruses and pathogens in areas where the water supply is inadequate. Workers involved in wastewater treatment are also at risk of infection (Silva et al., 2020). Nevertheless, the half-life of SARS-CoV-2 in wastewater has been reported to be highly dependent on temperature (Hart et al., 2020), UV ozone (Yao et al., 2020), and chlorine-based disinfectants (Zhang et al., 2020). The half-life of SARSCoV2 in hospital effluents has been estimated to range from 4.8 to 7.2 h at 20°C, and the nucleotide sequence agreement and spike glycoprotein similarity between SARS-CoV-2 variations is 99.9% (Hart et al., 2020).

2. Renewable energy

Since 2000, wastewater treatment systems powered by renewable energy have drawn significant attention (Fig. 7) (Yang et al., 2021). Due to their ability to reduce carbon dioxide emissions, these systems can also provide sanitation and reuse of water in remote and isolated areas. In addition, renewable energy (solar, geothermal, wind, and tidal/wave) has become increasingly affordable in recent decades (Fig. 8), which has led to its widespread use and application in wastewater treatment facilities (Kollmann et al., 2017). In the event that energy grids are down after a natural disaster, a wastewater treatment system powered by renewable energy might be the best option (Ali et al., 2020). However, water, resources, and potential energy can all be recovered by membrane processes in wastewater treatment. There are several different types of membrane processes depending on how they are driven (Zhang et al., 2019): First, the filtration process can be pressure-based (microfiltration, ultrafiltration, nanofiltration, and reverse osmosis). Secondly, electricity is required for electrodialysis, and other electro-membrane processes and a gradient of concentration (forward osmosis) is essential. Finally, using membrane distillation and membrane evaporation to produce a thermal gradient.

For wastewater treatment and reuse, renewable energy can be utilized in various ways, such as electricity generation, heat generation (thermal gradient), wind flow (for evaporation), and concentration gradient generation ((Charcosset 2009)).

2.1. *Using renewable energy to generate electricity in wastewater treatment*

Renewable Energy Sources are commonly recognized as beneficial in increasing the sustainability of energy use at WWTPs and reducing the cost of energy supply (Fig. 9). Using on-site renewable energy sources, such as wind, solar, water, and waste generated on-site, can effectively reduce the energy supply's economic costs (Mook et al., 2014). Eco-friendly technologies like bioenergy must be added to WWTPs in order to improve environmental efficiency.

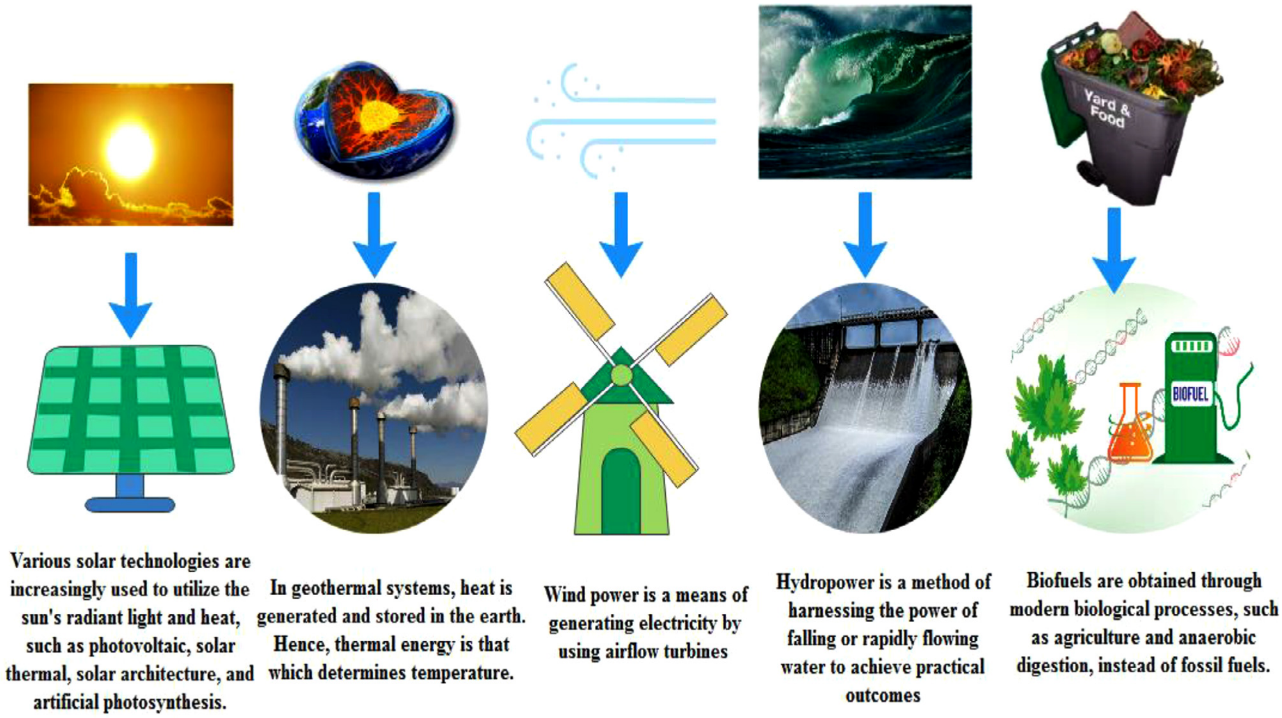


Fig. 7. Rate of growth of renewable energy in wastewater treatment worldwide.

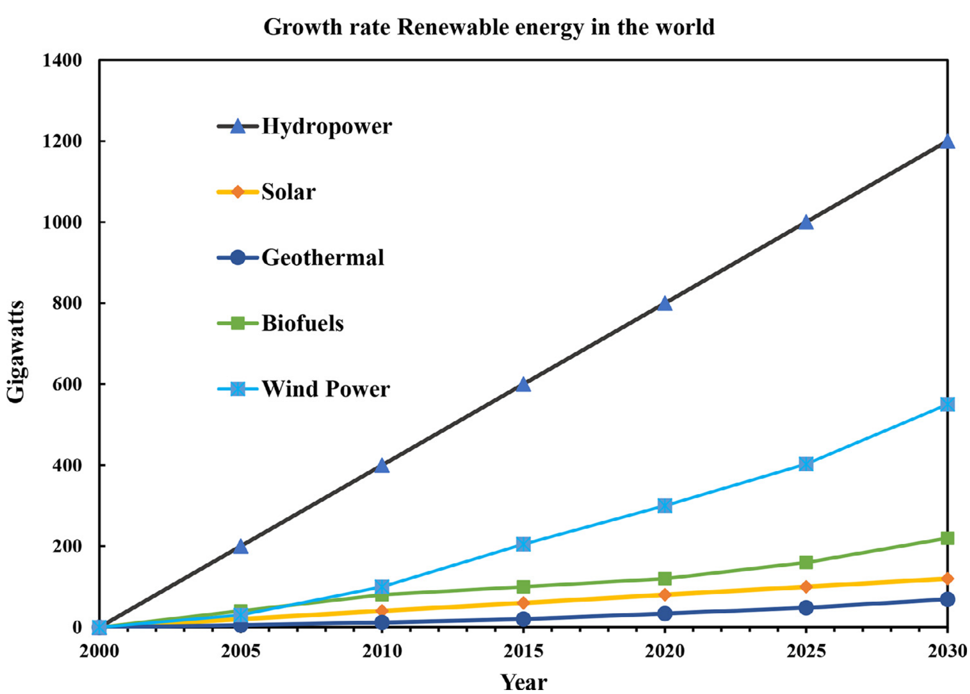


Fig. 8. There is a wide observation that renewable energy sources are widely used today (Ghandriz et al., 2021).

Solar photovoltaic (PV) systems have gained popularity due to converting sunlight into electric currents without implying any environmental harm (Makrides et al., 2010). This source has several uses, including the water pump (Meah et al., 2008), lamp (Enaganti et al., 2020), chargers of batteries (Masoum et al., 2004), and supply of electric utility grids (Bhandari et al., 2014). Since the mid-1990s, the production of PV modules has risen dramatically at an astounding rate, indicating PV systems' great potential for the present and future (Parida et al., 2011). Previous tests have demonstrated that the PV system is capable of producing power regardless of the weather. In partial cloudy conditions, PV is capable of even generating 80% of their potential energy (Pali and Vadhera, 2020), while in hazy or humid conditions, they can generate 50%; and in heavily overcast conditions, they can still generate 30% (Ishii et al., 2013).

Typically, two types of PV systems exist stand-alone systems and are connected to the grid. Stand-alone PV systems require batteries to operate, and such systems can be installed in remote areas. In contrast, grid-connected PV systems use the local power grid and produce solar electricity distributed through an independent power provider. For public sector installations of PV systems, a variety of financial incentives are

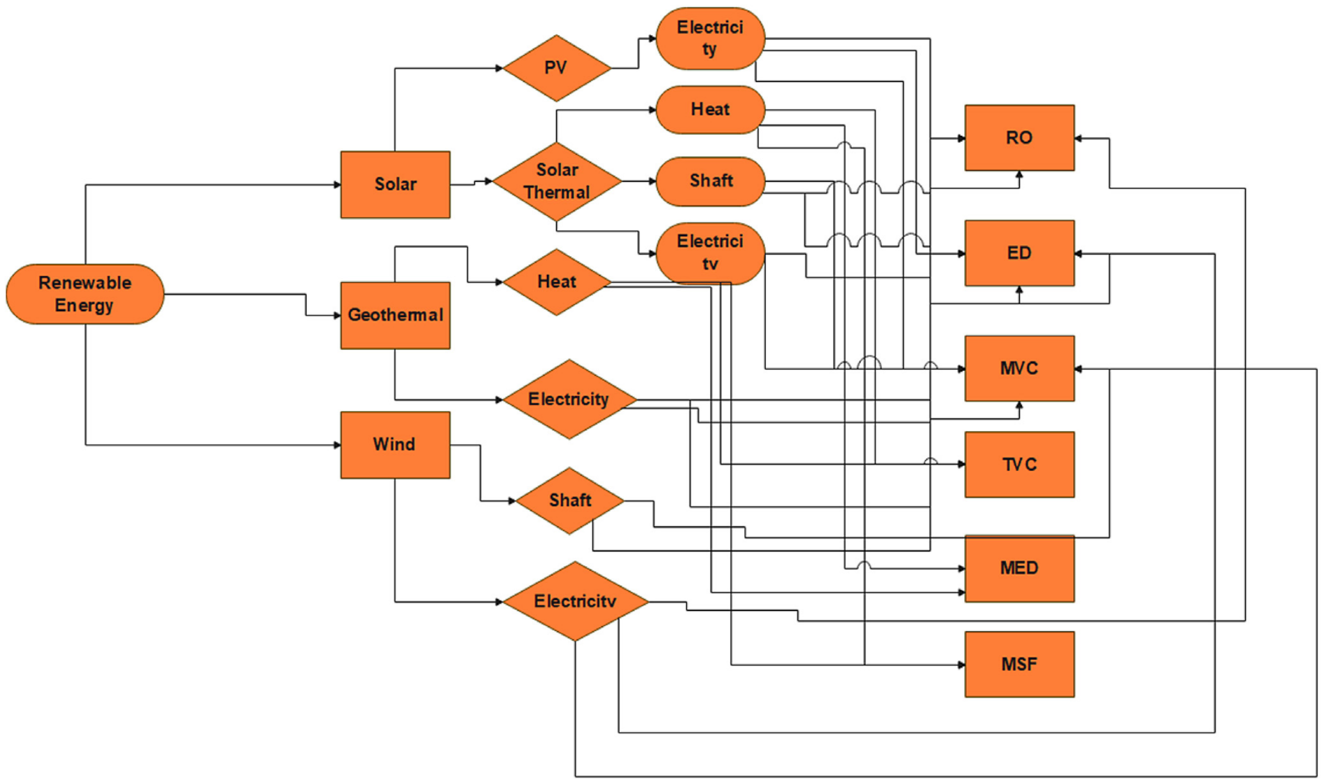


Fig. 9. Potential utilization of Renewable Energy for wastewater treatment and desalination purposes.
Abbreviations: PV=Photovoltaic, RO=Reverse Osmosis, ED=Electrodialysis, MVC=Machinal Vapor Compression, MED= Multi-Effect Distillation, MSF= Multi Flash Distillation, TVC= Thermal Vapor Compression.

Table 2
Contaminants removed by electro-coagulation and electro-flotation during wastewater treatment.

Method	Sewage	Removal (%)	Using electrode and experimental	Refs.
	Oil wastewater treatment	COD [a] =50 Color=95	Anode: Al, Cathode: Fe Voltage: 12V, Current density: 20 mA cm2 pH: 6, Duration: 10 min Temperature: 22 C, influent COD: 48500 mg/L, Initial color: 2120 m1	(Inan et al., 2004)
	Textile wastewater treatment	COD=80	Anode: Al, Cathode: Al Temperature: 25 C, influent COD: 3422 mg/L	(Can et al., 2006)
	Tannery wastewater treatment	COD=50 TOC=50 Nitrate= 32	Anode: Al, Cathode: Al pH: 6.8, Duration: 60 min Temperature: 23 C, influent COD: 46500 mg/L	(Feng et al., 2007)
Electrocoagulation	Dairy wastewater treatment	COD=60 Nitrate= 84	Anode: Al, Cathode: Al pH: 6.8, Duration: 30 min Current density: 43 mA cm2 Temperature: 22 C	(Tchamango et al., 2010)
	Synthetic wastewater treatment	Nitrate= 92	Anode: Steel sheet, Cathode: Steel sheet, Current density: 36 mA cm2 Temperature: 20 C pH =7	(Escobar et al., 2006)
	Synthetic wastewater treatment	Nitrate= 92	Anode: Fe, Cathode: Fe Influent Nitrate= 2500mg/l, pH: 7 Temperature: 20 C, Current density: 1 mA cm2	(Lacasa et al., 2011)
	Leachate Wastewater treatment	COD=50 Nitrate= 39 BOD [b] =84	Anode: Fe, Cathode: Fe Temperature: 21 C, Current density: 5 mA cm^2, Duration: 90 min	(Li et al., 2011)
	Synthetic (Juice and oil) Wastewater treatment	Oil=90	Anode: Graphite rod, Cathode: Ss screen Current density: 20 mA cm2, Duration: 30 min	(Araya-Farias et al., 2008)
Electroflotation	Velvet wastewater treatment	COD=90 BOD=93	Anode: Al, Cathode: Al pH:5, Duration: 20 min, Voltage: 20 V	(Belkacem et al., 2008)
	Synthetic wastewater containing heavy metals		Anode: Ruo/Ti plate, Cathode: Ss screen	

[a] Chemical Oxygen Demand [b] Biological Oxygen Demand.

Table 3
Applications of various technologies for Renewable Energy in WWTPs.

Types of technologies for renewable energy production	Critical applications and major obstacles	Refs.
Solar photovoltaic (PV) for electricity generation	• The implementation is impacted by the magnitude and the site of the WWTP. • This technique is more predominant in small-scale plants as well as rural and decentralized areas where large spaces are accessible. • There is a significant difference in day and night discharge rates, and there is slight night-time wastewater discharge.	Di Fraia et al. (2020); Strazzabosco et al. (2019); Han et al. (2013)
Solar energy and biogas in anaerobic digestion to produce heat and electricity	• Linking these technologies can enhance electricity control techniques' ability and promote the electricity self-sufficiency of WWTPs and/or cities. • Solar installations require huge investments.	Di Fraia et al. (2020); Strazzabosco et al. (2019); Arcos-Vargas et al. (2019); Mehr et al. (2017).
Solar PV cells combined with an electrochemical process	• The combination of electrochemical systems and solar cells increases the sustainability of wastewater treatment systems. • Additionally, solar heat also enhances the oxidation of endothermic organic reactions.	Di Fraia et al. (2020); Mook et al. (2014); Nie et al. (2020).
Wind aerators	• Notwithstanding the substantial investment expenses, wind aeration systems in sewage treatment plants are considered attractive due to their low maintenance requirements, low sludge production, and low operating costs. • It may not work without a backup when there is not sufficient wind. • Wind tends to diminish at night, thus might not work well for forceful aeration requirements.	Horan et al. (2006).
Low-temperature heat from geothermal energy	• Geothermal energy can be used in cold weather zones to increase wastewater temperature to 30°C to boost treatment performance or heat anaerobic digesters. • Potential greenhouse emissions.	Di Fraia et al. (2020).
Geothermal energy to produce heat and electricity	• It uses heated groundwater to heat liquids with a lower boiling point than water, generating steam that powers turbines and generators. • Geothermal energy is location-specific.	Rubio et al. (2020).
Hydropower generation technology	• It helps reclaim clean and sustainable energy from wastewater while reducing carbon emissions by avoiding fossil fuel-based energy. • Limited plant locations and susceptible to droughts.	Atallah et al. (2020); Kidmo et al. (2021); Lei (2021).
Biogas power generation technology	• Heat is generated from biogas combustion, either in front of or in a gas engine or gas turbine. • It is essential to project the heat flow characteristics regarding temperature, power, energy carriers, and different heat applications, among other general attributes. • Few technological advancements.	Karamichailidou et al. (2022); Sechi et al. (2021);

available in an effort to promote the use of renewable energy sources and boost environmental awareness (Singh 2013, Sobri et al., 2018).

A few researchers have examined PV systems as power sources in electrochemical systems (Table 2). Some have used textile wastewater as an electrolyte solution to reduce organic compounds (such as BOD, COD and so on) because organic compounds are incapable of breaking down during biological treatment. Textile wastewater contains azo dyes and their intermediates, which can be carcinogenic, toxic, and mutagenic. Hybrid PV is an electrochemical process that is able to remove organic compounds while also generating hydrogen gas at the same time (Ganiyu et al., 2019, Strazzabosco et al., 2019).

PV systems typically include PV modules, batteries, a controller, and an inverter. It is converted into electric energy (direct current) upon absorbing solar radiation on the PV module (Table 3). After the electric energy has been produced, the power is sent to the batteries through a regulator. In the case of batteries, the regulator prevents them from being overcharged or discharged excessively. Backup electricity is generated using stored solar energy at night and during periods of low solar radiation (Sahu et al., 2016). During low solar radiation periods, (Dominguez-Ramos et al., 2010) reported that a PV setup without batteries is inefficient to treat water, due to the inadequate backup power supply. Furthermore, the treatment procedure can only be performed during the day without a battery. Among other things, an inverter converts direct current (DC) into alternating current (AC) for devices that need AC power.

2.2. Membrane processes utilizing renewable energy

It is practical to use renewable energies for membrane processes either directly (for example, to draw energy from the wind to evaporate membranes) or indirectly (for instance, to drive reverse osmosis using the electricity generated by the wind turbine). In general, the direct use of renewable energy is more energy-efficient because energy conversion involves energy loss. However, the process and application restrict the necessary energy form (Charcosset 2009). Typically, membrane processes are driven by electricity in order to treat wastewater. Membrane bioreactors (MBRs) are increasingly popular used renewable energy-driven membrane systems. Since numerous examples of photo-

Table 4
Evaluation of each membrane used in wastewater treatment.

Membrane technology	Membrane type	Pore size (μm)	Pressure required (bar)	Contaminants removed	Benefits	Drawbacks
MF	Porous	10−1–10	1–3	Bacteria, fat, oil, grease, colloids, organics, micro-particles, algae, clay, etc.	• Consumption of less energy, the cost of investment is relatively low.	• The replacement of membranes and chemicals is more expensive.
UF	Micro Porous	10−3–1	2-5	Proteins, pigments, oils, sugar, organics, microplastics, colloids, viruses, etc.	• The Operating system is easy to use and starts up quickly. • Other contaminants have been removed from the water.	• If feed water quality changes, it could be adversely affected.
NF	Tight Porous	10−3–10−2	5-15	Pigments, sulfates, divalent cations, divalent anions, lactose, sucrose, pesticides, sugars, detergents, soaps, radionuclides, cysts, viruses, etc.	• Having a large production capacity.	• Conventional treatment is essential for a successful recovery. • A High-pressure operation may cause mechanical failures.
RO	Semi Porous	10−4–10−3	15-75	All contaminants, including monovalent ions, aqueous salts.		

voltaic and wind-powered MBRs have been installed worldwide, there have been no technology barriers to their implementation (Zhang et al., 2019). Atlantic City was the first to build a WWTP powered by solar and wind, including GE Zenon's membrane bioreactor (Sutherland 2007). Microfiltration (MF) or ultrafiltration (UF) are typically applied in MBR technology, with pore sizes ranging from 0.4 to 0.02 μm ((Li et al., 2017)). Despite the fact that the application does not provide any information on the scale of energy consumption related to municipal MBRs, which Krzeminski and colleagues report in their study as 0.5-0.7 kWh/m^3 (Krzeminski et al., 2012). Therefore, one solar panel should produce approximately 0.7 kWh/m^2 of electricity to treat one cubic meter of wastewater by MBR during the day in light of the PV pane's electricity generation intensity of 0.7 kWh/m^2 (Björklund et al., 2001). Due to its ability to filter via ultrafiltration membranes, MBR effluent is capable of filtering particles, suspended solids, bacteria, and dissolved compounds; therefore, it can meet the standards for direct discharge or surface water recharge (Wei et al., 2014). Nanofiltration or reverse osmosis (RO) is one way to remove organic compounds and salts from water (i.e., to produce industrial water or indirect potable water). It typically takes 0.77 kWh of energy to refine one cubic foot of wastewater using NF or low-pressure RO (Obotey Ezugbe et al., 2020).

UF, NF, and RO membrane processes (driven by pressure) are not the only way to reclaim domestic wastewater (Table 4). In Forward osmosis (FO), a dense membrane produces gradients of concentration to drive the membrane, ensuring that almost all wastewater pollutants are retained. The desalination concentration or thermal evaporation method can be applied to recover the diluted draw solution used in the FO process. For instance, the thermal evaporation method (membrane distillation or MD) uses solar energy for power, while desalination-concentration (RO or electrodialysis or ED) uses electricity from photovoltaics (PVs) or a wind turbine (Qtaishat et al., 2013, Obotey Ezugbe et al., 2020).

Recent years have seen a focus on resource recovery from wastewater. A bio-electrochemical cell can generate electricity using methane from the anaerobic degradation of nutrients (P, N, K). Membranes can recover nutrient elements. Recent studies have focused on phosphate recovery. Zhang et al.2009 have recovered phosphate using an electrodialysis stack explicitly designed for phosphate recovery (namely "electrodialysis," SED).

Due to the ability of ion exchange membranes to separate nutrients using electricity, they can be used to drive this process for resource recovery using renewable energy (Liu et al., 2017). As with a conventional fuel cell, microbial fuel cells (MFC) rely on an ion-exchange membrane (Asensio et al., 2018). In a microbial fuel cell, mixed and pure cultures of cellulose-degrading bacteria generate power from cellulose. The process is beneficial in two ways: organic pollutants are degraded, and bioelectricity is produced; simultaneously, using electrochemistry, wastewater is treated for removing and recovering nutrients ions. (Zhang et al., 2014) developed a bio-electrochemical system to recover phosphate. Bio-electrochemical systems consist of electrodes and ion-exchange membranes that remove phosphate and ammonia using an electric field generated by bioanodes and hollow cathodes. Bioelectrochemical systems have been investigated for wastewater resource recovery (Bajracharya et al., 2016). It has shown that the system involves both electricity generation and separation, which is complex and causes the investigation to become increasingly complicated due to the interdependence of these two processes. On the other hand, in comparison with chemical catalysis, BES is capable of producing high-value chemicals at a lower cost using an inexpensive catalyst (protein catalysis).

Membrane filtration systems such as MF and UF, which are used in advanced wastewater treatment, have the potential to block the transmission of SARS-CoV-2 effectively. Furthermore, a modular membrane system structure can help eliminate SARS-CoV-2 from effluent using current WWTPs. The effectiveness of MF > 50 nm and UF 2–50 nm membranes at removing SARS-CoV-2 depends on the distribution of pore diameters in relation to the target virus. Thus, UF membranes can effectively remove SARS-CoV-2 with a diameter of 10 to 100 nm under certain conditions (Kitajima et al., 2020). In addition, SARS-CoVs can be eliminated based on membrane surface characteristics based on electrostatic and hydrophobic interactions. An MBR can use ultrafiltration to enhance viral removal (not just for SARS-CoV) and steric removal, adsorption, and inactivation during biological treatment. Due to this, MBRs have shown to be more effective at removing enteric viruses (removing up to 6.8 logs) than conventional WWTPs (removing up to 3.6 logs). SARS-CoVs could also be entirely removed by high-pressure membrane systems using tighter and denser membranes (pore sizes <2 nm) such as NF and RO (Lv et al., 2006).

2.3. Solar energy

There are many renewable energy sources worldwide, but solar energy is the most abundant. Some studies indicate that solar power probably can meet the entire world's energy needs from just 1% of the arid and semi-arid areas. According to reported data, many the Middle East and North Africa areas receive solar insolation of 5-7 kW h per solar day (Fig. 10). They are generally characterized by abundant brackish or seawater but lack sufficient freshwater, so solar energy is ideal for desalination (Yang et al., 2018). Desalination of saline water can be conducted directly by using solar energy or converting it into electricity. The first type mainly includes solar stills, humidification devices with dehumidification, solar chimneys, etc., while the second type primarily uses photoelectric modules (Kasaeian et al., 2019). Solar power is converted into electricity with photovoltaic (PV) cells (Singh 2013). In order to improve the efficiency of these cells, solar energy can be concentrated primarily. Although PV cells are attractive in cost-effectiveness, overall lifecycle, and energy storage, they are not yet practicable. It is

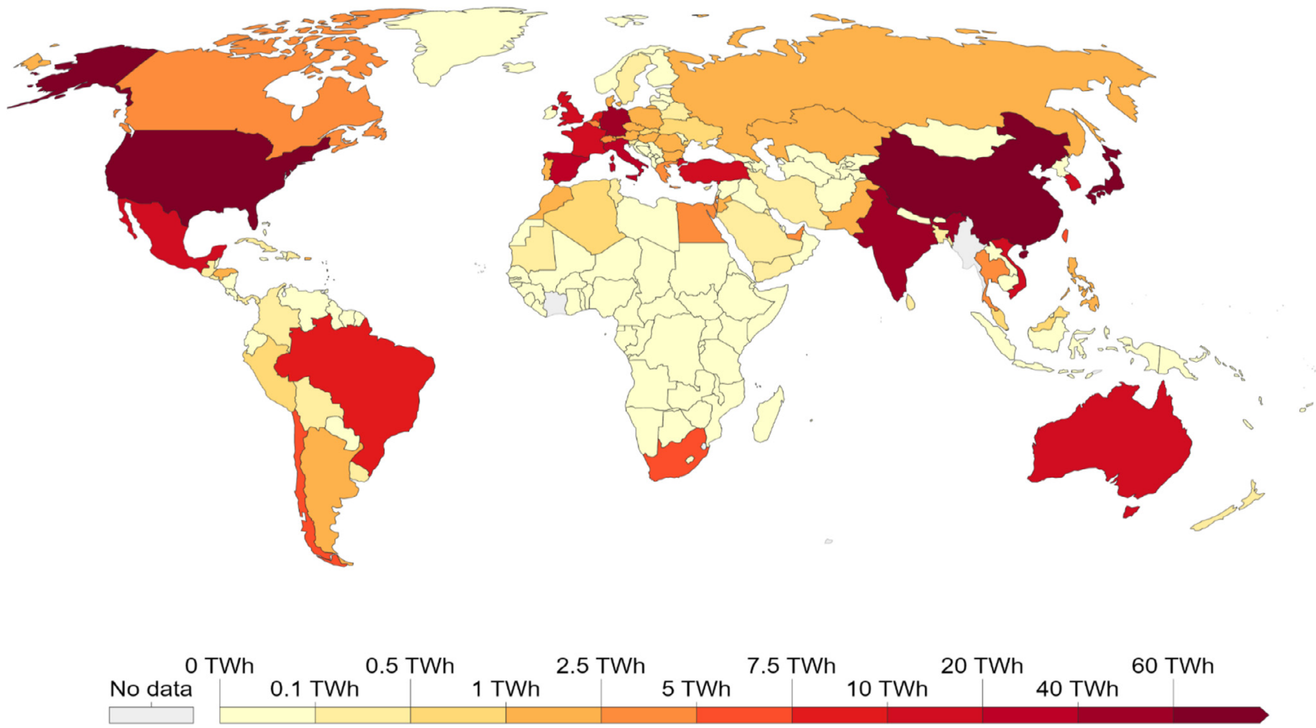


Fig. 10. Solar power generation (worldwide), 2020. The amount of electricity generated by solar is measured as terawatt-hours (TWh) per year. Source: Our World in Data based on BP Statistical Review of World Energy & Ember, BP Statistical Review of World Energy: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html– Ember: https://ember-climate.org/data/.

Table 5
Pros and cons of solar and geothermal energy.

Renewable energy	Pros	Cons
Solar energy	• The power produced by solar panels is not polluting and does not emit any greenhouse gases.	• The cost of solar has dropped dramatically over the last ten years, becoming more cost-effective every day. Solar has high initial costs for material and installation and a long ROI (although Solar's costs have dropped dramatically).
	• Become less dependent on foreign oil and fossil fuels.	• There is not yet 100% efficiency, so a great deal of space is needed.
	• A source of renewable electricity can be generated on cloudy days; likewise, even during the winter.	• Solar power is not available at night; therefore, large batteries are needed.
	• Compared to utility bills, returns on investment are much higher.	• It is more expensive to run devices directly from DC power.
	• Solar panels do not need maintenance for over 30 years.	• The energy output of cloudy days is lower than on sun days.
	• The solar industry employs manufacturers, installers, etc., benefiting the economy.	• The production of solar energy is lower during the winter.
	• A home or building can live entirely off the grid if all the power generated is sufficient.	
	• Powering homes and buildings with solar energy or even a car can be achieved with solar power.	
Geothermal energy	• Relatively green energy source. • Reliable sources of renewable energy. • Renewable and sustainable. • Stable and dependable energy supply. • Not dependent on weather conditions. • No noise pollution. • Significant future expansion prospects. • Low maintenance efforts and costs.	• High upfront capitals for construction and installations. • Extraction of geothermal energy may cause greenhouse emissions. • Geographic dependence. • It is essential to have a large quantity of water on hand. • Geothermal reservoirs can be depleted eventually. • For geothermal energy, high temperatures are required. • Earthquakes may be caused by geothermal energy production.

possible to use PV thermal to produce thermal energy and electric power simultaneously. Solar energy is used nowadays to generate steam to run desalination units manually. Renewable desalination has gained high popularity because of solar energy's abundant availability and the fact that it can be converted to either electric or thermal power (Table 5) (Wang, 2010).

2.4. Solar energy in wastewater treatment

As one of the renewable energy sources, solar energy is most widely used in order to reduce sludge water content. Despite the low costs and little maintenance, open solar drying beds were still used (Zhang et al., 2018). Currently, greenhouse dryers are being used since they are more energy-efficient and aid in reducing pathogens and dry matter content. In greenhouse dryers, the air around the sludge or the bottom of the greenhouse can be heated to increase drying efficiency (Abdel-Ghany et al., 2011, Prakash et al., 2014). Supplemental heat can be generated through solar energy, such as through hot water pipes inside the greenhouse, a solar water heater, or a heat pump that uses treated wastewater as a heat source. In addition to integrating solar energy with other energy sources, there are also proposals to improve thermal drying. In order to dry sludge and conduct anaerobic digestion, biogas is generated by anaerobic digestion of sludge coupled with a parabolic trough collector fueled by biogas. CHP has provided enough electric energy for WWTP to meet its demand (Bennamoun 2012, Shao et al., 2015).

The demand for freshwater has risen exponentially in recent years. Globally, freshwater is of great importance. However, there are many ways the environment and humans misuse water, including wasting it on agriculture. In addition, manufacturing has become increasingly dependent on water in recent years. As a result, water is becoming scarce. In particular, this technique has been developed to treat non-biodegradable or regenerative wastewaters that cannot be successfully treated using the industry's conventional biological or medicinal treatment processes. A heterogeneous photocatalytic method was used to oxidize untreated effluent from the pharmaceutical industry to improve the efficiency of impurity oxidation and preserve economics (Pandey et al., 2021a,b). Typically, raw materials used for treating wastewater include ozone, chlorine, hydrogen peroxide, and ferrous iron (Fenton's reagent) and hydrogen peroxide (Kannan et al., 2016).

Chemical pollutants such as persistent organic pollutants are found in industries, household wastewater effluents, and water leachate from wastewater (Loganathan et al., 2020). These filters need to be replaced to ensure that our water sources remain clean. More and more techniques were implemented throughout the year and used to kill the toxins. Researchers have studied photocatalytic detoxification as an alternative method for treating polluted water since 1976. Based on quantum mechanics, photocatalysts have a well-defined energy level structure (Tsoutsos et al., 2005).

Wastewater from industrial brines can now be treated with a solar-powered system. Wastewater from industrial brines can now be treated with a solar-powered system. An integrated system for treating industrial brine wastewater using solar energy has been developed, producing valuable benefits for the community. Water treatment techniques based on membranes and evaporation were integrated into the developed system. Various methods of evaporation, such as falling film and forced convection, were employed. Thermodynamically, this system is analyzed under varied operating conditions using energy and exergy approaches (Sansaniwal 2019, Li et al., 2021).

Solar system generation could be applied to future desalination (Sharon et al., 2015), sterilization (Li et al., 2018), and chemical purification (Yang et al., 2018). Since photon control and thermal insulation have developed accelerating, solar stems are being manufactured by minimizing radiation, convection, and convective losses while improving light transmission. As a result of studying the standard transpiration mechanism in plants, researchers have proposed creating a 3D artificial transpiration system with all components, which minimized heat loss and relied predominantly on angular light absorption, producing maximum solar system performance under a single sun. As well as generating purified water from polluted heavy metal ions, the artificial transpiration process results in a low carbon footprint, recycling of heavy metals, and recycled heavy metals. Various technical solutions based on solar energy were presented, focusing on recent developments in energy recovery technology (Marcelino et al., 2015, Borges et al., 2016, Pandey et al., 2021a,b).

2.5. Effect of solar energy on SARS-CoV-2 in air and wastewater treatment

Using solar energy for air purification is becoming more common in recent years since it provides excellent UV and other thermal radiation sources that kill microorganisms and control pollution. There are several publications describing photocatalyst solar systems for air and water purification. A solar-energy-based photocatalyst degradation of formaldehyde (HCHO) was investigated by (Litter et al., 2020). A TiO_2 sol-gel film covered the inner surface of the borosilicate glass reactor. TiO_2 was used as a light source, which provided a 5-Log reduction in HCHO in about 60 min when using solar UV-A with 0.6 mW/cm^2. According to (Ma et al., 2019) air purification is required in houses, cars, offices, and other occupied spaces. HCHO is a major carcinogenic component of indoor air pollution, primarily composed of volatile organic compounds (VOCs). When the appropriate temperature is reached, HCHO can be oxidized to CO2 and H_2O by TCR using transition metal oxides and noble metals found in many building materials. In order to use solar energy as a heating source, Sun et al. (2020) investigated the TC oxidation reaction using MnOx-CeO_2. An experiment was conducted to study the effects of initial HCHO concentration, indoor air temperatures, solar irradiation, and ambient temperatures on the oxidation process. According to the study, the initial HCHO concentration was vital compared to solar irradiation or ambient temperature. Using solar energy made it possible to significantly reduce oxidation times, significantly reducing the threshold limit for the Chinese Indoor Air Quality (IAQ) standards (Wang et al., 2004).

Disinfestation methods based on solar energy lower the risk of transmission from high concentration sites, particularly in tropical areas with an abundance of solar energy. These methods are the most economical and practical for hospitals, isolation wards, and medical centers. However, solar energy wastewater disinfection in several aquatic environments is feasible and widely applicable. Water disinfection by solar energy is a sustainable approach that is widely endorsed for disinfecting water. In addition, there are primarily three factors that determine the impact of solar radiation: solar intensity, physical and chemical properties of wastewater, and type of virus. Solar radiation is higher than 2000 kWh/m^2/y per year, making solar energy an available energy source. Several mechanisms can be used to disinfect wastewater. For instance, the direct mechanism involves photon absorption directly by viruses or endogenous components like proteins, nucleic acids, and other biomolecules. Thus, one advantage of UV treatment for water treatment is that it is an effective disinfectant, as it is able to kill most waterborne pathogens, as well as a few pollutants that are relatively resistant to the treatment. Under UV light, phosphodiester bonds and links with molecules are broken, which leads to a breakdown of the viral genome and proteins. Accordingly, the viral particles lose their ability to infect and replicate.

Furthermore, UV light is one of the most effective methods for disinfecting biologically contaminated water. Compared to other methods like chlorination, it does not generate harmful by-products and controls the growth of microorganisms. According to their wavelengths, UV types include UVA (315-400 nm), UVB (280-315 nm), and UVC (100-280 nm), abbreviated as UVA, UVB, and UVC (UVA photons are low-energy, while UVC shows that photons are powerful enough to damage the DNA of pathogens). However, Inactivating viruses occur through UV-B (280–315 nm) radiation; and hence, they absorb the UV-B radia-

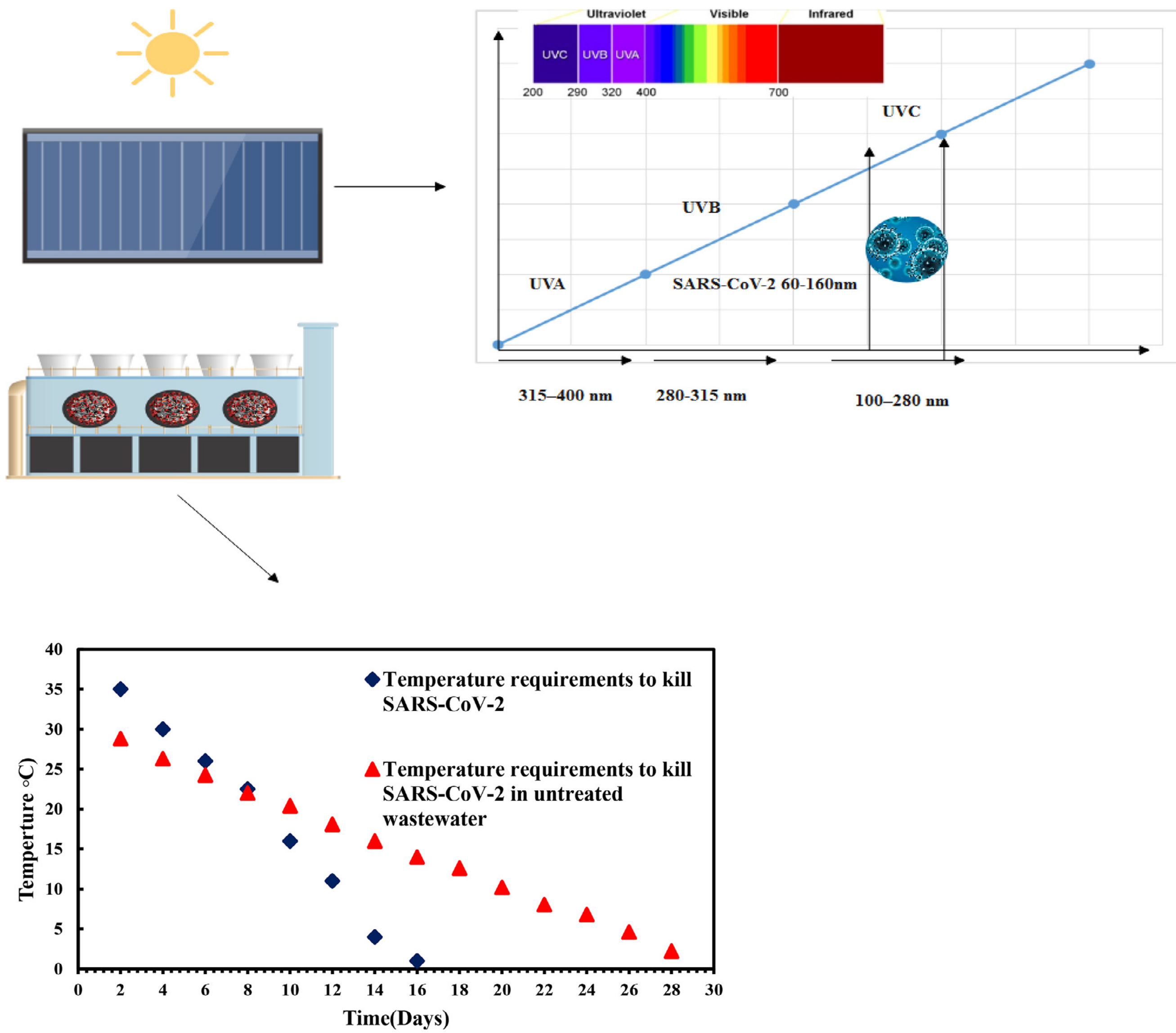


Fig. 11. SARS-CoV-2 can be removed effectively from wastewater via solar energy2.6 Geothermal energy.

tion. Viruses cannot be effectively disinfected by solar radiation because most UVB wavelengths cannot reach the earth's surface; it may exacerbate the problem when UV intensity decreases. Under 550 W/m^2 at 45°C in the solar water disinfection simulation, coxsackievirus was wholly inactivated after two hours (Heaselgrave et al., 2011), but it could not be entirely inactivated by exposing it to 75 W/m^2 for 6 h at a maximum of 34°C (Alotaibi et al., 2011). In a recent study, (Nicastro et al., 2020) investigated how UV-B in sunlight inactivates viruses in various populated cities worldwide. The result showed that the COVID-19 virus inactivated in the summer comparatively more rapidly, indicating that solar radiation has a vital role in its occurrence and spread. Finally, according to several reports, more than 90% of COVID-19 viruses in world cities were inactivated by exposure to mid-day solar radiation after 11-34 min (Fig. 11).

An example of geothermal energy is the provision of steam and hot water from the Earth and then used to generate electricity. Geothermal energy is suitable for many applications due to the wide range of Earth's temperatures (Fig. 12). In order to use geothermal energy (Table 5), either vaporize liquids with lower boiling points so that steam can be manufactured or, based on the quality of the geothermal energy, heat a turbine directly. Geothermal energy technology has been proven for electricity production, although it is not widely used. Currently, geothermal energy serves more than 60 million people in 24 countries worldwide, providing approximately 10,000 megawatts of energy (Asif et al., 2007). A significant advantage of geothermal energy is that it can be used directly for desalination, even though its net installed capacity is less than wind power. A geothermal well can be used for desalination if the depth exceeds 100 meters (Goosen et al., 2010). Geothermal energy is an excellent energy source for areas with excellent resources for water. A high-pressure geothermal source can be used straight up for mechanically driven desalination, but high-temperature geothermal fluid can generate electricity to power RO or ED plants. Water's thermal desalination can be performed using geothermal heat from a low-temperature energy source. In comparison with other renewable energies, geothermal energy provides uninterrupted thermal power.

In comparison to other renewable energy sources, geothermal energy is unlike most other RES. It is not affected by intermittency; it is a suitable source of electricity due to its reliability and continued availability. Furthermore, the process is relatively standard on islands, usually located at the juncture of two plates or originate from volcanic activity, making them very promising. During the geothermal process, heat is ex-

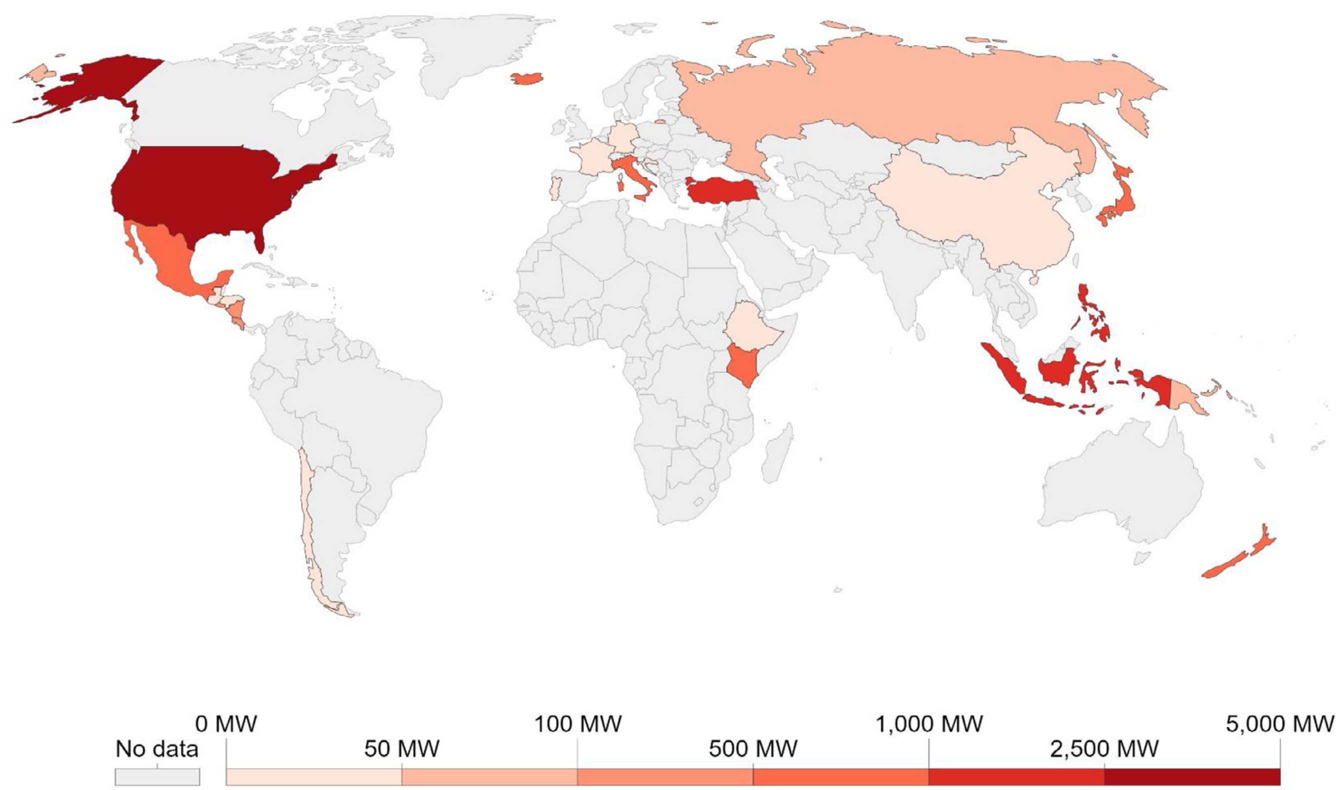


Fig. 12. Installed geothermal energy capacity (worldwide), 2020. The cumulative installed capacity of geothermal energy, is measured in megawatts. Source: Statistical Review of World Energy - BP (2021), OurWorldInData.org/renewable-energy • CC BY, Link: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

tracted from porous or fissured rocks within Earth's crust which contain hot water or steam. Applications depend on the temperature of geofluids. For electricity generation, high-temperature fluids are used, such as conventional (150-350°C) or binary (90-200°C) power plants, while low- and medium-temperature fluids are used for industrial, agricultural, district heating, or space heating. In the future, binary geothermal power plants will likely become more popular due to the abundance of low-temperature geothermal energy sources and geo pressured (Di Fraia et al., 2019, Di Fraia et al., 2020).

2.7. Effect of geothermal energy on SARS-CoV-2 in wastewater treatment

Thermo-catalytic Inactivation (TCI) has been proposed to disinfect water against bacteria and viruses. When transition metal oxides such as MnO2, CuO, and TiO2 are used as thermal catalyst in Thermo-catalytic Reactors (TCR), a temperature range of 40-80°C is required (Chen et al., 2018). Even at room temperature, disinfection can be accomplished using noble metals such as Pt, Pd, Au, and Ag for TCR. As a result, higher temperatures adversely affect SARS-CoV-2 and its conservative surrogates (Guo et al., 2021). Much research showed that the temperature range for SARS-CoV-2 disinfection is the same as that suggested for TCR reactions for water purification. Researchers pursuing thermal inactivation to combat SARS-CoV-2 are in the early stages of this research (Harussani et al., 2021). Under various environmental conditions, the TCI of a surrogate for human norovirus, a virus, takes 40 days to remain on diaper or feces for viral survival. Increase the temperature from 18°C to 30°C without any catalyst, and the inactivation time can be shortened to even one hour at 56°C, reducing the time from 40 days to 24 days. In addition, the virus appears to be susceptible to freezing and thawing but remains stable at room temperature (Parsa et al., 2021).

3. Key challenge and future research needs in the use of solar energy to treat

All types of waste management are energy-intensive, which is challenging to achieve during the global energy crisis. Plentiful solar energy is proactively used to dispose of solid and liquid waste (Pandey et al., 2021a,b). Technologies such as solar pathogenic organic destruction, solar photocatalytic degradation, solar thermal desalination, and distillation are used to treat liquid waste (Ugwuishiwu et al., 2016). Despite the benefits of integers in each method, specific problems need to be addressed. Fig. 13 illustrates the significant challenges associated with solar wastewater treatment.

- Discarding waste after wastewater treatment has a negative impact on the environment. As a result, recycling technology must be used to treat waste residues, which increases overall cost-effectiveness.
- Large-scale treatment facilities do not yet exist because of high capital costs. This is very relevant to the study for further analysis of the model before building any wastewater treatment plant.
- The downside of solar energy is that wastewater is treated only during the day, while wastewater treatment plants are ineffective at night. It is more expensive to install energy storage systems in wastewater treatment plants.
- Wastewater treatment plants are required to comply with Environmental Impact Assessment (EIA) regulations and therefore vary by location. As a result, firms lack skilled workers to boost productivity (Sansaniwal, 2019).
- Due to the lack of industrialization of laboratory research, scientific innovation in solar wastewater treatment is lagging.
- Solar desalination is a reliable way to disinfect brackish water into drinking water. Even though the system is straightforward, the solar

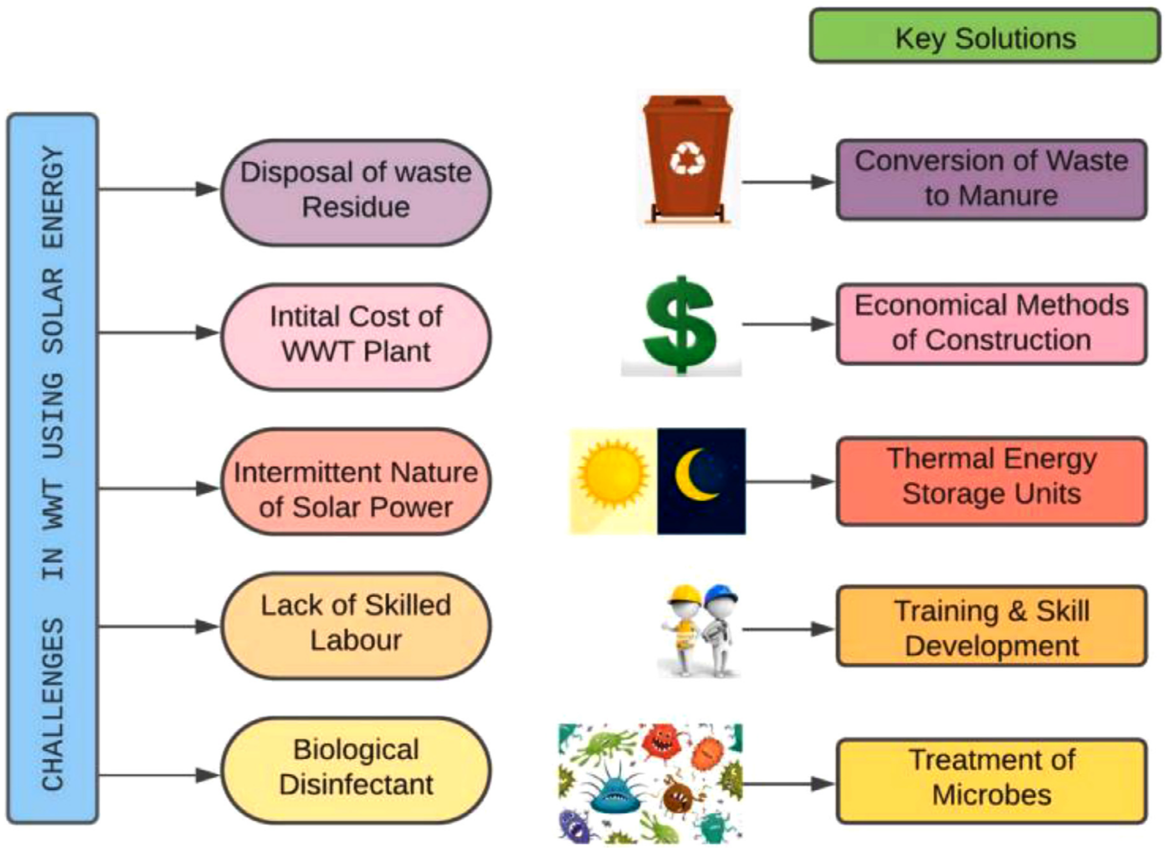


Fig. 13. Solar energy uses for wastewater treatment: critical challenges (Pandey et al., 2021a,b).

evaporation process must solve various problems, such as lacking a cost-effectively operational feasible application component.

- Removing heavy metals from liquid waste involves further technological development to improve efficiency.
- For wastewater treatment plants that use solar energy, water must also be treated for biological decontamination and to remove offensive odors.
- As SARS-CoV-2 is very sensitive to temperature, it can survive within its environment for up to two days at low temperatures (4°C), room temperatures (20–25°C), and hot temperatures (33–37°C), but not at 56°C or 70°C where it lasts for less than an hour (30 minutes and 5 minutes, respectively) at those temperatures.
- Due to the lower rate of solar UV in cold seasons (specifical winter), solar stills are not suitable for cold seasons (specifical winter). A sufficient amount of UV is essential to prevent pathogens from spreading by vapor and prevent pathogens from growing on solar stills.

Solar energy could be used for wastewater treatment to enhance treatment significantly and solve water scarcity if researchers and scientists pay close attention to the above issues.

4. Conclusions

According to reports in several parts of the world, it is highly likely that novel Coronavirus SARS-CoV-2 will appear in water and wastewater. In water, coronaviruses are inactivated by the temperature and are sensitive to moisture. SARS-CoV-2 is most commonly transmitted through symptomatic people's stools to water, sewage, and wastewater. A current drinking water treatment process inactivates and destroys SARS-CoV-2 in water efficiently and effectively. SARS-CoV-2 can be detected using frequent sewage and wastewater monitoring, thus mitigating the threat of pathogen transmission and adverse health effects.

Furthermore, as part of the ongoing fight against COVID-19, this review article discusses the physical inactivation mechanisms that can be used to inactivate the SARS-CoV-2. Detecting viruses in the water is alarming for scientists because the virus could spread faster through the water, worsening the country's crisis during monsoon season. It also includes information on physical inactivation methods such as UV-inactivation and thermal-inactivation, which are used to eliminate pathogens and VOCs in air and water. As a method of disinfecting air and water, solar energy, an excellent source of UV and heat, is shown in COVID-19. This review article further aims to answer specific questions to understand better the application of renewable energy such as solar and geothermal energy in wastewater treatment. An important question to be resolved is the scientific details, feasibility, and methods studied so far for the mechanisms used to break down pollutants in wastewater while minimizing the spread of SARS-CoV-2 using solar and geothermal energy. Critical analysis of critical issues such as pollutants present in industrial and domestic wastewater, wastewater treatment methods, and environmental benefits of wastewater treatment.

Consent to publish

This version has been approved by all other coauthors.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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