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Authors: Seçil TUTAR ÖKSÜZ

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Life Cycle Assessment of Microbial Electrolysis Cells for Hydrogen Generation Using TRACI Methodology

Seçil TUTAR ÖKSÜZ*[1]

Abstract

Bioelectrochemical systems (BESs) use electrochemically active microorganisms to convert the chemical energy of organic matter into electrical energy, hydrogen, or other useful products through redox reactions. Microbial electrolysis cell (MEC) is one of the most common BESs which are able to convert organic substrate into energy (such as hydrogen and methane) through the catalytic action of electrochemically active bacteria in the presence of electric current and absence of oxygen. In the past decades, BESs have gained growing attention because of their potential, but there is still a limited amount of research is done for the environmental effects of BESs. This study initially provides an update review for MECs including general historical advancement, design properties, and operation mechanisms. Later, a life cycle assessment (LCA) study was conducted using a midpoint approach, which is TRACI methodology with EIO-LCA model to identify the potential impacts to the environment whether adverse or beneficial using the MECs to produce hydrogen with domestic wastewater as a substrate. The results show that the cumulative negative impacts were substantially larger than the positive impacts by contrast with the expectations, and the cumulative output data show that human health non-cancer impact provides the highest environmental effects than others mainly because of the inorganic chemicals, pumping and wastewater recycling equipment step. In addition, global warming potential and smog creation potential are also elevated mainly due to electricity usage, inorganic chemical and glassware reactor production. Later we are externally normalized each impact category to compare the results at the normalization level, and we again found that human health (cancer or non-cancer) potential provides the most negative impact on the environment in the MEC system originates on human health indicators.

Keywords: Microbial electrolysis cells, Life cycle assessment, Hydrogen generation, Wastewater treatment, TRACI

1. INTRODUCTION

The world population has continued to grow at a significant rate and is anticipated to exceed 9.7 billion by 2050 and nearly 11 billion in 2100 [1-3]. Related to urban development and population growth, there has been a significant increase in energy consumption [4]. According to the 2019 Annual Energy Outlook, crude oil reserves will run out by 2052, natural gas will run out by 2060,

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* Corresponding author: stutar@ktun.edu.tr
[1] Konya Technical University/Faculty of Engineering and Natural Sciences/Environmental Engineering Department
ORCID: https://orcid.org/0000-0002-2713-7379

and coal will run out by 2090 if the fossil fuels's consumptions continue at the present rate [5]. Another challenge related to extensive consumption of fossil energy resources has been associated with a significant increase in the mass of greenhouse gases (GHG) (carbon dioxide, ozone, nitrous oxide, methane, water vapor, etc.), which are known to inhibit long-wavelength radiation from escaping into space, into the atmosphere. The effects of global warming has been already observed as higher sea levels, more severe storms, dirtier air, higher wildlife extinction rate, higher death rates, and so on [6]. Consequently, alternative sustainable energy resources are becoming more important because of declining fossil energy sources, global warming threats, environmental pollution, and reliance on fossil fuels exporting countries. On the other hand, related to urban development and population growth, especially in developed countries such as the US, wastewater generation has been significantly increased [7]. According to Connor, R. et al. (2017), around 20 percent of the world's wastewater is discharged into water bodies with applying treatment every day [8]. Discharging of untreated wastewater can cause waterborne illnesses such as diarrhea, hepatitis, cholera, meningitis, to name a few. It can also cause environmental risks, mainly because of eutrophication. In addition, GHG emissions, especially in the form of nitrous oxide and methane, can form decomposition of these waste streams [2, 9, 10]. According to the studies, untreated wastewater generates a GHG footprint roughly 3 times higher when the same wastewater is properly treated in a wastewater treatment plant. Even though the conventional wastewater treatment processes have advantages, such as low installation cost, fast start-up, flexible operation, and high wastewater treatment efficiency, they also have some drawbacks such as high energy requirements for their installation, maintenance, and operation [11]. Conventional aerobic treatment processes also produce large amounts of sludge, which is also costly to dispose of or treat, and may account for 35-60% of the total operating cost [12, 13]. According to the Environmental Protection Agency (EPA), about \$25 billion is used to treat domestic wastewater and another \$300 billion is spent to improve publicly owned treatment works every year in the United States [14]. Hence, current approaches to wastewater treatment account for 3-4% of the total energy consumption in the US with public water treatment services; other developed countries have similar statistics [15, 16]. For this purpose, improving current wastewater treatment systems with new sustainable technologies is an essential need to improve sustainability in wastewater besides eliminates adverse effects of global warming. At this point, producing hydrogen from wastewater is becoming very important since it is a clean and efficient fuel, especially if it is produced from sustainable energy sources.

Bioelectrochemical systems (BESs) have recently gained great attention as a promising technology that generates electricity, hydrogen, or other useful chemicals by oxidizing biodegradable organic matters using electrochemically active bacteria [10, 17]. Although many other applications of BESs have been studied, including harvesting value-added products (e.g., H2 and CH4); removing specific contaminants in wastewater such as heavy metals; and niche applications (i.e. biosensors), BESs have mainly been studied in terms of two applications, which are wastewater treatment and electricity generation during the last years. The main advantages of BESs are that they can be operated at room temperature, have high fuel conversion efficiency, and simultaneously wastewater treatment. Among BESs, microbial electrolysis cells (MECs) is a novel technology, which are able to convert organic substrate into energy (such as hydrogen) using electrochemically active bacteria by consuming electrical energy in the absence of oxygen [18]. Literature shows that hydrogen productions rates in MECs are between 80 to 100% if compared to other processes such as fermentation and water electrolysis [19, 20]. Also, effective applications of MECs can provide economic and environmental benefits. In this context, this study aims to analyze the environmental effects of microbial electrolysis cells for hydrogen production. In this study, we summarize the historical development of the MECs, operational principles, general design properties, application areas, advantages, and challenges. Further, different MECs studies were reviewed to compile data, which aim to help us to evaluate, compare and validate the feasibility of this emerging technology. Therefore, we obtained data from previous studies which aim to generate hydrogen while treating wastewater and conduct a life cycle assessment of available MECs.

2. MICROBIAL ELECTROLYSIS CELLS

Event hough the idea of using microorganisms to produce electricity was first proposed in the early twentieth century by Potter, but first Cohen and later Davis and Yarborough constructed the first real MFC in 1962 [21, 22]. Although the interest in these systems slowed down until the 1990s, BESs have received more attention because of potential applications. BESs have been studied for a variety of applications, and they share the same principles, which is an oxidation half-reaction at the anode in which electrons are lost and a reduction half-reaction at the cathode in which electrons are gained [23]. MEC is one of the main type of BESs. In the anodic compartment, electrochemically active bacteria oxidize organic matter to generate electrons and protons. The generated electrons are transferred to the electrodes by three possible electron transfer processes including direct electron transfer via membrane redox proteins [24-26], mediated electron transfer via indigenous or exogenous redox molecules [27, 28], and conductive pili or nanowires that is formed on the bacteria cell surface connected to anode surface. In the meantime, the protons diffuse from the anode to the cathode through a separator. At the cathode, protons are reduced with a supply of additional voltage to produce hydrogen gas (Figure 1) [29]. For example, if glucose (C6H12O6) is used as an electron donor (298 oK, 1 bar, pH=7), the reactions occurring in each electrode can be expressed as in Eqs. (3) - (4) below:

Oxidation reaction at anode:
C6H12O6 + 6H2O → 6CO2 + 24H+ +24e-
Eo = -95 mVAg/AgCl5 (1)

Reduction reaction at cathode:
24H+ + 24e- →12H2
Eo = -613 mVAg/AgCl (2)

Since the theoretical total cell potential (Eocell =Eocat-Eoan) is negative when glucose is used as a model electron donor under standard conditions, the reaction is not spontaneous. However, when a voltage is added (> 518 mV vs. Ag/AgCl), the reaction can be completed to form hydrogen gas.

As discussed in the previous section, BESs can effectively remove organic matter from wastewater within a reasonable amount of time. Even though MECs still not fully functioned in technology yet, MECs have great potential to become alternative traditional wastewater treatments methods.

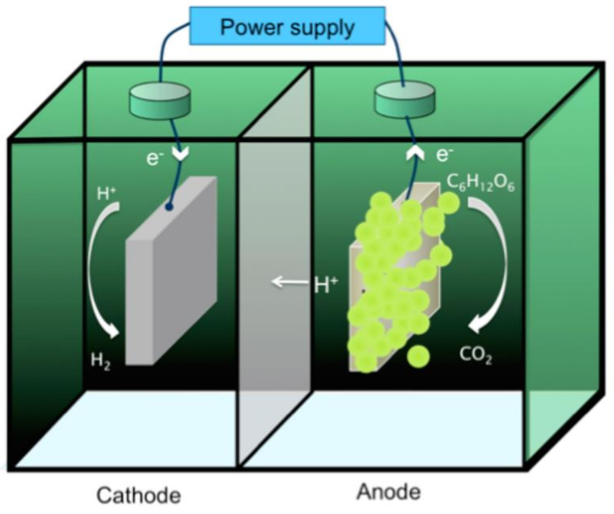

Figure 1 Schematic representation of a microbial electrolysis cell

Meanwhile, the hydrogen production rate was reported as 15 L/L/d with 100% of purity in a very first pilot-scale MEC study to treat domestic wastewater [30]. Another study showed that MECs can accomplish above 75% COD removal with real domestic wastewater applications with also an associated energy consumption which is reported below conventional wastewater technologies [19]. However, hydrogen recovery is not sufficiently high for practical applications of MECs with real wastewater. Also, when industrial wastewaters are used as substrate, MECs recover higher hydrogen due to the high concentration of organic matter in industrial wastewater, but these systems require some kind of amendment before being fed to the MECs. Besides wastewater, using different types of püre substrates results in generating other chemical products such as methane (CH4), ethanol (EtOH), and hydrogen peroxide (H2O2) besides hydrogen. Table 1 shows selected MECs studies that used different types of wastewater, COD reduction and hydrogen generation rates. On the other hand, pure substrates, such as acetate, tend to provide the highest hydrogen production rates comparing wastewater. However, the primary concern generally is producing hydrogen when treating wastewater using this technology.

Table 1
Selected MECs performance parameters

Substrate Type	COD reduction (%)	H_2 gen. rate ($m^3/m^3/d$)	Ref.
Domestic wastewater	58±3	0.28±0.04	[31]
Domestic wastewater	25.4	0.041	[32]
Potato wastewater	79	0.74	[33]
Swine wastewater	75	0.9-1	[34]
Sludge wastewater	44.92	0.038	[35]
Dairy wastewater	92	0.2	[36]
Acetate	-	3.12	[37]
Acetate	-	50	[38]

Especially, during the last few decades, numerous studies have been carried out in the field of MECs, increasing its performance. MECs have advantages over other technologies because they have diverse applications including harvesting value-added products (e.g., H2); removing specific contaminants in wastewater such as heavy metals. However, as mentioned previously there are also limitations including low wastewater treatment efficiency in some of MECs, high energy loss, low coulombic efficiency and scale-up problems and cost of electrodes, etc. [39]. Even though these limitations, prospects of MEC technology are promising since several pilot-scale reactors have been developed, and research on MECs is continued [20]. Nevertheless, there have been many studies about MECs especially during the last decade, there are no many studies focused on the environmental benefits of MECs for hydrogen production using domestic wastewater.

This study initially aims to provide an update review for MECs including general historical advancement, design properties, and operation mechanisms. Then, a life cycle assessment (LCA) study was conducted using The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) characterization factors with EIO-LCA (The Economic Input-Output Life Cycle Assessment) model to identify the potential impacts to the environment whether adverse or beneficial using the MECs to produce hydrogen with domestic wastewater as a substrate.

3. METHODOLOGY

A life cycle assessment (LCA) is a methodology that investigates the environmental impacts of a product or process instead of the other technologies. LCA is also called cradle-to-grave analysis since it considers the product's or process's all the stages during the entire lifetime including manufacturing, construction, operation, repair, and dissemination. According to the International Organisation for Standardisation (ISO) in ISO 14040, LCA has four different basic stages including (1) goal and scope definition; (2) inventory analysis; (3) impact assessment; and (4) interpretation. However, we rearranged the algorithm by including reviewing and collecting technical data as a very first step and normalization of the data as another step, which is necessary for the selected midpoint approach in this study (Figure 2).

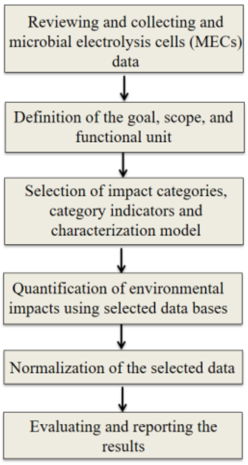

Figure 2 Methodology of life cycle assessment

The first part of a LCA study generally starts with defining the goal of the study, its scope and functional unit [40]. The ISO 14040 standard expresses that the goal of the study definition may include telling the intended use of the study, the reason for carrying the study, and to whom the results are aimed to be communicated and used as a comparative analysis [41]. According to the definition of the goal explained above, the goal of this current study is to identify that it is beneficial from an environmental point of view to converting wastewater to hydrogen using MECs. This study aims to provide sufficiently broad information related to environmental consequences. The primary aim of the study is to evaluate and validate the feasibility of this emerging technology. Therefore, the intended audience of the study will be the researchers and technical experts in the area of BESs technology [42]. In addition, the scope step should define a statement of the reason of the study, with detail and depth and show that applications of the results. When explaining the scope of the study, the functions of the product system; the functional unit; system boundary; life cycle impact assessment methodology; inventory data; data quality requirements; critical review considerations and comparison between systems should be considered and described [43].

Once the goal and the scope of the study are chosen, the next step is to set the functional unit, which should be chosen based on the goal of the study. The functional unit should provide a reference unit of comparison that the system (or product) can be compared to provide an equivalence [44]. Therefore, the primary aim of this study is to achieve higher pure hydrogen generation, so our function is hydrogen production, and the functional unit is pure hydrogen generation rate (m3-H2 /m3-reactor per day). However, if the projected aim is only wastewater treatment, then the functional unit will also change accordingly. In this case, the functional unit will be organic compound removal rate (mg-COD/m3 - reactor per day). According to ISO 14040, system boundary is specified to determine which unit processes that is included in the product system. The initial boundaries of the system will be determined by the goal and the scope of the study. An overall scheme of MEC process and its possible system boundary for LCA is shown in Figure 3.

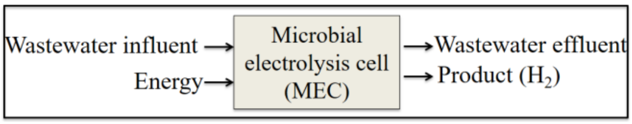

Figure 3 System boundary of a microbial electrolysis cell

After defining the goal, scope, and functional unit, the second step of LCA is life cycle inventory (LCI) step, which involves the data collection and calculation input and output flows to complete the inventory. This data collecion is actually the first step for a complete characterisation of the different streams to obtain a detailed inventory of all the inputs, outputs, emissions and other environmental impacts [45]. LCA studies sometimes can have data availability and/or quality problems within this phase. In our study, the preliminary inventory data is collected from previous MECs studies in the literature, laboratory experiments, and/or LCA databases. In addition, background information (e.g. chemicals production processes) is normally provided by free LCI databases such as Agribalyse, USDA, NEEDS, ELCD, bioenergiedat, USLCI.

The inventory of the MEC system has a long list, so we divided the process into three stages construction stage, operation stage, and electricity. While the construction stage includes pump, pumping equipment, plastic pipe, pipe fitting equipment, plastic, rubber products, electrode materials (carbon and graphite products), membrane, wiring, glass container, the operation stage includes wastewater and chemical requirements. The current study also assumes that construction and operation parameters such as temperature, retention times, pH, reactor configuration, etc. are in static conditions. Also, sludge and nutrient removal (nitrogen and phosphorus) were allocated in this study.

In an LCA, an important aspect to be considered is the selection of the appropriate impact categories, which is in life cycle impact assessment (LCIA) stage. Two LCIA methods are used in the LCA as midpoint and endpoint approach. Endpoint approach (i.e. EPS, Ecoindicator 99). The primary aim of the endpoint approach is to be understood as issues of environmental concern, such as ecosystem, resource availability, human health, climate change, and etc. while categorizing them in damage level. On the other hand, midpoint approach (i.e. CML 2002, EDIP 2003, TRACI) consider the environmental impact at a level in cause-effect chain, which is also called problem level [46]. The main difference between midpoint and endpoint methods is that the way how category indicators show the impact categories [47].

TRACI is one of the midpoint approaches was developed by United States Environmental Protection Agency (US EPA), which draws simple cause and effect chains to demonstrate the point at which each impact category is characterized, and is one of the most used midpoint approaches in the US. Basically, TRACI method is used for general uses like environmentally sustainability or environmental pollution control. Different impact categories considered in this methodology include Global Warming Potential (GWP), Acidification Potential (AP), Human Health Criteria Air Potential (HHCAP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP), Smog Creation Potential (SCP), Ecotoxicity Potential (ETP), Human Health Cancer Potential (HHCP), Human Health Non-Cancer Potential (HHCP), and Non-Renewable Energy (NRE) [48]. Among these common impact categories GWP, AP, HHCAP, ODP, and SCP are air-related categories, but EP, ETP, and HHCP are air, water, soil-related categories. After the impact categories are selected, the inventory data are classified to the selected categories, which is essential to define characterization factors. These characterization factors should reflect the relative contribution of an LCI result to the impact category indicator result into common units (such as kg SO_2 equivalent for acidification potential) [49]. In this study, we will identify significant impact categories by comparing them using normalization step to present suggestions to reduce the environmental impact can be made in the interpretation part. Detailed information about TRACI method can be found in the literature.

In our study, we also used The Economic Input-Output Life Cycle Assessment (EIO-LCA) model, was developed by Carnegie Mellon University, which estimates the materials and energy resources required for, and the environmental emissions resulting from, activities in the economy [50]. EIO-LCA provides us several outputs data based on raw materials that are used in the construction, operation, and electricity stages of MEC. We also have to indicate that electricity data includes electricity usage during operation. However, even though EIO-LCA does not provide us with the exact value of electricity usage during the production period of the construction stage, we know that a significant amount goes directly to electricity usage during construction [51].

Table 2
Selected MECs performance parameters

Impact category	Construction	Operation	Electricity
GWP (CO_2 eq.)	438,58	376,01	294,50
AP (SO_2 eq.)	4,62	1,66	1,69
HHCAP (PM10 eq.)	2,47	0,462	0,335
EP_{air} (N eq.)	0,144	0,019	0,025
EP_{water} (N eq.)	4E-04	8,25E-04	4,5E-06
ODP (CFC-11 eq.)	2,1E-03	7,55E-04	0
SCP_{air} (O_3 eq.)	93,10	7,55E-04	13,60
ETP_{low} (2,4-D eq.)	1,05	4,80E-04	3,41E-03
ETP_{high} (2,4-D eq.)	0,102	0,005	0,003
$HHCP_{low}$ (Benzene eq.)	0,101	0,049	0,05
$HHCP_{high}$ (Benzene eq.)	1,33	1,19	0,015
$HHNCP_{low}$ (Tolune eq.)	237,3	12,95	0
$HHNCP_{high}$ (Tolune eq.)	347,2	740,50	0
NRE (J)	0,016	0,005	0,025

3. RESULTS AND DISCUSSION

After all inputs and outputs data (construction, operation, and electricity based data of a MEC system) were obtained mainly from EIO-LCA software (Table 2), the results were scaled as needed and summed up all outputs. In this study, midpoint categories were GWP (CO2 eq.), AP (SO2 eq.), HHCAP (PM10 eq.), EP (N eq.), ODP (CFC 11 eq.), SCP (O3 eq.), ETP (2,4D eq.), HHCP (benzene eq.), HHNCP (toluene eq.), and NRE (MJ). Figure 4 shows the results from EIO-LCA output in dimessionless units, as summed total score. The impact results indicate wide dispersion of the effects between selected midpoints depending on material input, electricity usage, and emissions produced that occurred for each process. The last part of the current study aims to understand the implications of the selected method and draw conclusions.

GWP, SCP, and HHNCP are the most contributed overall impact categories in the current study (Figure 4). Results from the LCA of MEC study demonstrated that the most significant impact category of the inventory in terms of contribution to GWP, which compares emissions of greenhouse gasses using CO2 equivalents. The sources of GWP can be antropogenic and/or naturogenic as the other impact categories. The predominant contributors of GWP are inorganic chemicals (376,01 kg CO2 eq.), electricity consumption (294,50 kg CO2 eq.), and glassware reactor (316 kg CO2 eq.) The second significant impact category is HHNCP, which expressed the possible increase of toxicological health risks by releases of the substances except for cancer. For HHNCPhigh, the production of inorganic chemicals is the highest contributor to impacts (740,5 kg toluene eq.), while the second-highest contributors are pumping and wastewater recycling equipment (325,5 kg toluene eq.). On the other hand, the dominant contributors of HHNCPlow are pumping and wastewater recycling equipment (159,5 kg toluene eq.) and wires (57,5 kg toluene eq.), which use in the preparation of the electrodes. In the EIO-LCA model, the outputs are expressed as low and high estimates for some impact categories including ETP, HHCP, and HHNCP in TRACI methodology. For the HHNCP, EIO-LCA outputs for toluene equivalent emissions low and high are estimated. In the current study, we use the average of low and high results while representing it in Figure 4. And also another high significant impact category is SCP (also known as photochemical oxidation), which can define as the additional formation of ground-level ozone by releasing nitrogen oxides (NOx) and particulates. Even though the electricity (13,6 kg O3 eq.), pump equipment (10,06 kg O3 eq.), and inorganic chemicals (8,4 kg O3 eq.) create considerable impacts, the highest contributor is glassware equipments (61,50 kg O3 eq.), which are used as MEC reactors. Atmospheric emissions from melting activities, which are directly related, is the major source of envionmental impact during the glass production.

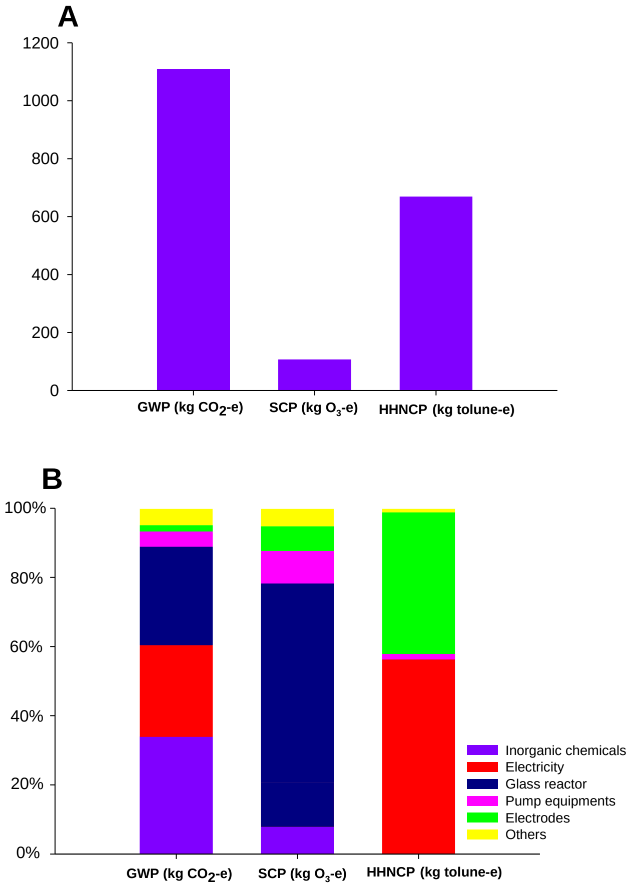

Figure 4 (A) The cumulative results from EIO-LCA output. (B) Percentage of the impact categories based on different materials and electricity

Figure 4A only demonstrates the selected impacts categories based on the EIO-LCA output. However, the other impact categories are shown in Table 2 because these impact categories have low impacts, so it was difficult to plot in the same graph. It is also important to add that ODP does not include nitrous oxide emissions in TRACI methodology, so the environmental impact related to ODP was not high as expected [52].

Even though the selection of impact categories, category indicators, characterization models, classification of the results, and characterization are mandatory elements, normalization, grouping, weighting, and data quality analysis are optional elements in LCA. When we interpret the impact scores normalization process may help us for an additional step. We know that normalization factors are important for relating results to a common reference, so the midpoint and endpoint results are compared at the normalization level. Therefore, reporting the results with a better base is possible. In this study, we used the normalization factors, which were obtained from a study Ryberg, M. et al. (2014) conducted in [47]. They reported updated normalization factors for the TRACI method of US EPA using both US 2008 and US 2008-Canada 2005 based on US and Canadian emission and resource data-based inventory. Therefore, TRACI contains normalization data for the following reference systems: US 2008 and US 2008-Canada 2005, and we normalized the relative to the US 2008 annual per capita by dividing the indicator results by the selected reference values (Table 3) [48] .

Table 3
Selected MECs performance parameters

Impact category	Unit	Normalized Value
GWP	kg CO_2 eq.	7,4E12
AP	kg SO_2 eq.	2,8E10
EP	kg N eq.	6,6E9
ODP	kg CFC-11 eq.	4,9E7
SCP	kg O_3 eq.	4,2E11
ETP	kg 2,4-D eq.	2,3E10
HHCP	kg benzene eq.	1,7E3
HHNCP	kg tolune eq.	1,1E4

Figure 5 shows the externally normalized values of selected midpoints. We found that the highest impact category relative to US 2008 normalization values is HHNCP, which is found 6,5x10-2. As mentioned above, EIO-LCA outputs for toluene equivalent emissions for HHNCP are estimated as low and high. Therefore, we use the average of low and high results while representing the normalized data. Similarly, HHCP provides us with the second-highest normalized impact data with 7,9x10-4. For the current study, the highest normalized midpoint score was human health (cancer or non-cancer) potential, which indicates that the most negative impact on the environment in the MEC system originates on human health indicators.

Figure 5 shows that the other total normalized impact scores of GWP, AP, EP, ODP, SP, and ETP have higher environmental effects than other potentials (HHCAP and NRE). According to Fig. 5, it is assumed to be chemical and other construction materials production and usage is a predominant source of especially GWP and AP while especially glassware production elevated SCP. Among these impact categories, AP is mainly formed by the SOx and NOx from the combustion of the fossil fuels. The normalized results also show that EP and ETP indexes show a tendency to increase.

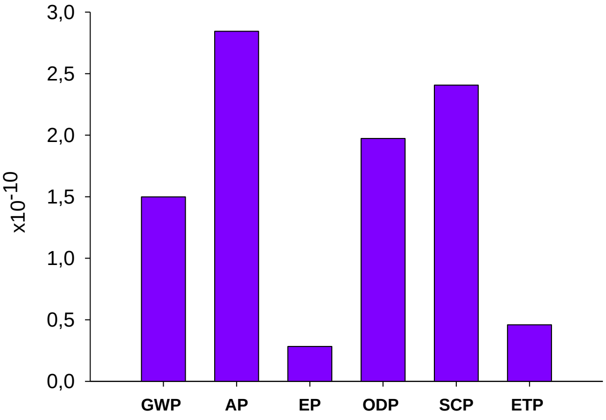

Figure 5 Externally normalized values of selected midpoints

As mentioned in the previous sections, the most important futures of MECs are hydrogen generation during wastewater treatment and also vastly reduce the amount of sludge produced. However, the current study only focused on hydrogen production when treating wastewater, and that’s why we obtained higher negative environmental impacts, in which hydrogen production rate is not high enough to obtain more positive environmental impacts. If the system boundary of this study expanded with including sludge removal, the results can move forward in the positive direction.

4. CONCLUSIONS

To summarize MECs have the potential for hydrogen generation while treating wastewater simultaneously. However, limited amounts of research are done on the environmental effects of MECs. This study provides an understanding of the environmental effects of MECs systems at the midpoint level as well as providing an update review for MECs including general historical advancement, design properties, and operation mechanisms. In this context, TRACI methodology was performed to identify the potential impacts of MEC on the environment at the midpoint level, which is the best available method for LCA. For internal optimization of the system, each impact category is externally normalized by using US normalization factors since it is very useful to examine which impact category has less or more significance in the overall system. The results provide that the positive environmental impacts were not larger as expected, which was mainly becuse of the construction stage. Even though MEC technology focuses on increasing hydrogen generation rate when treating wastewater, there should be other aspects that should be considered such as improving the operational parameters, innovating materials and, reducing the operational costs. Therefore, the emissions can be significantly reduced.

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The Declaration of Conflict of Interest/ Common Interest

No potential conflict of interest was reported by the authors.

The Declaration of Ethics Committee Approval

Ethics Committee Approval is not required.

The Declaration of Research and Publicatıon Ethics

In the writing process of this study, international scientific, ethical and citation rules have been followed.

Authors' Contribution

The authors contributed equally to the study.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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