Agronomy Research **24**(2), 19–37, 2026
https://doi.org/10.15159/AR.26.030

Greenhouse gas emissions in natural and constructed wetland systems

I. da S. P. Rochinha[1], D. de F. do Carmo[2], F. C. da Silva[2,*], Y. D. Jabrasi[1], D. Cecchin[2], L da S. Hamacher[2], A da F. Santiago[1], L. A. Nogueira[2] and H. Marotta[2]

[1]Federal University of Ouro Preto, School of Mines, Department of Civil Engineering, Campus Morro do Cruzeiro, Bauxita, Ouro Preto, MG, Brazil
[2]Fluminense Federal University, School of Engineering, Department of Agricultural Engineering and Environment, Praia Vermelha Campus, Praia Vermelha, Niterói, RJ, Brazil
[*]Correspondence: isabelarochinha@id.uff.br

Received: January 20th, 2026; Accepted: April 30th, 2026; Published: May 21st, 2026

Abstract. Constructed wetlands (CWs) are nature-based technologies that emulate the biogeochemical processes of natural wetlands (NWs) to treat effluents enriched with organic matter and nutrients, such as those from fertilized soils and urban sewage. However, previous evidence from individual ecosystems indicated that constructed wetlands may exhibit substantially increased greenhouse gas (GHG) evasion to the atmosphere compared to natural ones, representing a significant source of greenhouse gas emissions that has not yet been accounted for. This study aimed to evaluate the first global dataset of GHG emissions, encompassing methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O), from natural and constructed freshwater wetlands. Based on an extensive literature search from 1980 to 2020, it was found that median CH_4 and N_2O emissions were significantly higher in constructed wetlands than in natural wetlands. These emissions reached global medians of ~6.46 ± 5.72 and 0.20 ± 1.30 mg $m^{-2}h^{-1}$, for CH_4 and N_2O, respectively, representing a difference of ~517% and 200% compared to natural wetlands. The median CO_2 flux in constructed wetlands was ~171.20 ± 57.04 mg $m^{-2}h^{-1}$ and was not significantly different between the two groups. This indicates that effluent treatment conditions enhance the metabolic production of CH_4 and N_2O, due to intensified organic matter degradation. Furthermore, the dispersion in wetlands for CO_2, CH_4, and N_2O emissions also reflects the substantial spatial variability in GHG emissions. Therefore, sewage treatment efficiency and GHG balance must be considered for planning the design of constructed wetlands.

Key words: carbon dioxide, ghg emissions, methane, nitrous oxide, sewage, wetlands.

INTRODUCTION

Natural wetlands develop on seasonally or permanently flooded soils and are characterised by high levels of organic matter (OM) and nutrients (Ramsar Convention Secretariat, 2013). Although wetlands cover only 4 to 6% of the Earth's surface, they are

considered one of the most productive ecosystems in terms of biological diversity due to their high levels of OM and nutrients (Ramsar Convention Secretariat, 2013; Balwan & Kour, 2021).

These ecosystems exhibit intense microbial metabolic processes, which are often associated with high fluxes of greenhouse gases (GHGs) to the atmosphere. This occurs primarily through pathways involving the production and degradation of OM, which are linked to the sinks and sources of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Whiting & Chanton, 1993; Rychlik & Dąbrowska-Zielińska, 2011). Therefore, natural wetlands can exhibit both high rates of organic carbon (OC) sequestration and high rates of remineralisation into GHGs (Mendonça et al., 2017; Gallant et al., 2020).

Although constructed wetlands are designed to resemble natural wetlands in terms of their physical, chemical and biological processes, they receive high levels of OM and nutrient-enriched inffluents wastewater (Vymazal et al., 2006; Wallace & Knight, 2006; Vymazal, 2007; Chen et al., 2020; Ji et al., 2020; Kasak et al., 2020; Luo et al., 2020). The use of constructed wetlands for effluent treatment is particularly important in small communities or areas with diffuse sources where traditional sanitation is expensive (Yu et al., 2015; Ji et al., 2020). While constructed wetlands are recognised as a green technology for effluent treatment, GHGs may be emitted or consumed during the microbial processes such as organic matter degradation, methanogenesis, nitrification and denitrification (Mander et al., 2014a; Wu et al., 2015, 2016; Chen et al., 2020; Guo et al., 2020).

Although constructed wetlands can emit greenhouse gases during wastewater treatment, their emissions are generally lower than those reported for conventional treatment technologies such as stabilization ponds, anaerobic reactors and septic tank systems. For example, Boratto et al. (2021) reported that methane emissions from constructed wetlands in Brazilian municipalities with up to 20,000 inhabitants were approximately 80 times lower than those associated with conventional sewage treatment technologies. Similarly, Fuchs et al. (2011) observed that constructed wetlands tend to have a lower overall impact on GHG emissions compared with other treatment systems and highlighted that design factors such as the hydraulic regime can significantly influence environmental performance.Wetlands can be categorised based on the dominant aquatic vegetation and the water flow regime of the system. Aquatic plants are classified as floating, emergent or submerged. Constructed wetlands with emergent vegetation may operate as surface flow systems (horizontal or vertical), which can also be combined as hybrid systems. In horizontal flow systems, wastewater enters and gradually passes through the support material until it exits the system horizontally. In vertical flow systems, wastewater enters through the region where the plants are positioned and flows vertically through the filter medium until it reaches the outlet. In this system, the inflow can be either upward or downward. Surface flow systems generally use floating plants, as there is typically no support material; it is the aquatic vegetation that provides the substrate for the growth of microorganisms that degrade and metabolise contaminants (Vymazal et al., 2006; Vymazal, 2007).

Previous studies have demonstrated that environmental factors such as water level, temperature, precipitation and pH influence the GHG fluxes in natural and constructed wetlands (Clair et al., 2002; Chang & Yang, 2003; Mander et al., 2003; Hirota et al., 2004; Liikanen et al., 2006; Gleason et al., 2009; Silva, 2016). Furthermore, the

concentration of nutrients in the effluents, such as total nitrogen, ammonia, biological oxygen demand and chemical oxygen demand, may also cause different types of constructed wetlands to exhibit variable emissions of these GHGs (Mander et al., 2008; Wang et al., 2008; Vanderzaag et al., 2010; Bateganya et al., 2015; Hernández et al., 2018; Liu et al., 2019).

Many of these environmental factors can be optimised in constructed wetlands to prevent or minimise GHG emissions and achieve the highest level of nutrient removal and the lowest GHG emission rate. Natural wetlands have already been identified as carbon sinks, meaning they may sequester more carbon than they release in the form of CH_4 and CO_2 (Mitsch et al., 2013; Gallant et al., 2020; Jyoti Nath et al., 2022). Consequently, as the number of constructed wetlands worldwide has grown, it is important to assess their potential atmospheric impact (Chen et al., 2020).

Given that constructed wetlands receive effluents rich in OM and nutrients, inputs not found in natural environments, quantifying GHGs in constructed wetland systems is fundamental to defining design parameters. However, despite the increasing use of constructed wetlands for wastewater treatment, few studies have directly compared GHG emissions between natural and artificial wetlands, such as those by Singh et al. (2000), Jordan et al. (2016), Grinham et al. (2018) and Ollivier et al. (2019), and integrative assessments simultaneously considering CH_4, CO_2 and N_2O in both systems remain scarce. This represents an important knowledge gap regarding the environmental implications of using constructed wetlands as treatment systems. In this context, the present study addresses the following research question: how do greenhouse gas fluxes differ between natural and constructed wetlands, and what are the implications of these differences for the environmental sustainability of wetland-based wastewater treatment? Thus, the objective of this study was to assess the similarities and differences between natural and constructed wetlands regarding the fluxes of CH_4, CO_2 and N_2O gases, using literature data. This global dataset is detailed in Supplementary Table S1. Scientifically, this study contributes to the comparative synthesis of GHG fluxes across wetland types, while practically it may support the design and operation of constructed wetlands that better reconcile treatment efficiency and greenhouse gas balance.

MATERIALS AND METHODS

Study design

This study was based on a structured literature survey designed to compile reported GHG fluxes from natural and constructed wetlands. The review followed a predefined search strategy, including selected scientific databases, search terms, and eligibility criteria to identify studies reporting CH_4, CO_2 and N_2O fluxes. The objective was to obtain comparable datasets from the literature to allow a descriptive comparison between wetland types. A summary of the studies included in the dataset, including location, wetland type, gases measured, influent characteristics, macrophyte, and soil type, is provided in Supplementary Table S1. A comprehensive literature survey was conducted using the following databases: ScienceDirect, SpringerLink, Wiley, Web of Science, Gale, PubMed, Nature, SciELO, Taylor & Francis Online and CAPES. The objective of the present survey was to collate data on the mean fluxes of CH_4, CO_2, N_2O in natural and constructed wetlands.

The articles used in this study were collected between 1980 and 2020. Peer-reviewed articles were retrieved using the following search strings: 'wetland' or 'natural wetland', 'constructed wetland', 'artificial wetland' or 'treatment wetland', associated via the Boolean operator 'AND' with 'greenhouse gas', 'GHG', 'methane', 'CH_4', 'carbon dioxide', 'CO_2', 'nitrous oxide', 'N_2O'.

Initially, 227 studies were identified that matched the keywords or had the keywords in their titles or abstracts. From this database, primary data articles were selected for the purpose of data analysis. The articles reported GHG fluxes (CH_4, CO_2, and/or N_2O) from natural freshwater wetlands (according to the Ramsar classification) or constructed wetlands that treated effluents. The selection of articles was based on the inclusion of static chamber measurements and the presence of at least one described plant species.

In order to select the relevant studies, three further criteria were taken into consideration: firstly, that the reported GHG fluxes were in units of milligrams per square metre per hour (mg m^{-2} h^{-1} of CH_4, CO_2 and N_2O, or convertible units) or convertible units; secondly, that studies reporting on wetlands that had undergone restoration, i.e. wetlands where there had been 'manipulation of the physical, chemical, or biological characteristics of a former or degraded wetland to return its natural functions' (EPA, 2022), were excluded, on the grounds that it is understood that gas emissions can be influenced by restoration; and thirdly, that the wetland could not be a constructed wetland composed of a combination of vertical flow wetlands followed by horizontal flow, or vice-versa, i.e. a hybrid-type constructed wetland (Stefanakis et al., 2014). The final criterion was employed due to the distinct nature of the emission in these wetland types, which has the potential to influence the fluxes.

The totality of the data set encompasses 52 studies conducted on natural wetlands and 29 studies conducted on constructed wetlands. As illustrated in Fig. 1, a flowchart has been employed to elucidate the filters utilised in the bibliographic survey.

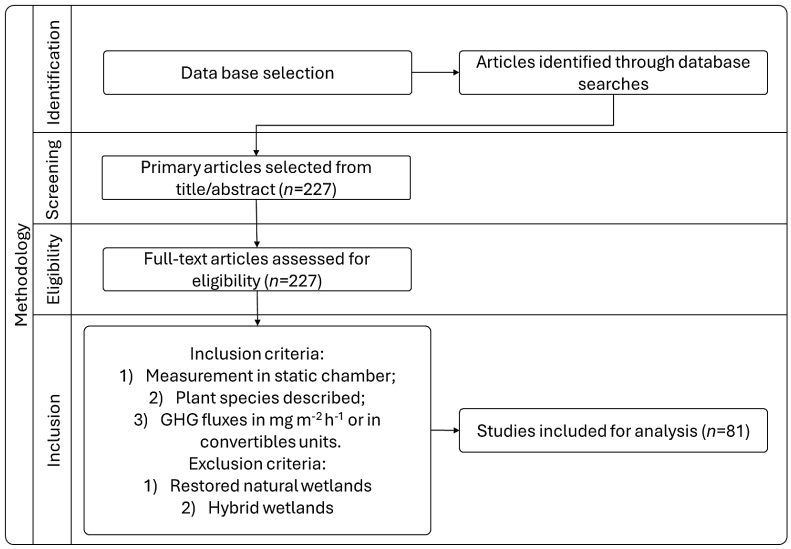


Figure 1. Flowchart of the study design.

The values of the GHG flux were collected in two ways. Firstly, they were collected directly from the text. Secondly, they were collected from tables or from graphs that had been digitised using the Graph Grabber version 2.0 program, when necessary (Benbow, 2020).

Data analysis

To perform a similarity test and understand how effluent treatment affects GHG emissions compared to the natural environment, analyses were performed using Prism statistical software (version 8.0.2). A *p*-value of less than 0.05 was considered statistically significant.

The normality and homoscedasticity of all the data were tested using the Shapiro-Wilk test. This dataset deviated significantly from a normal distribution, even after logarithmic transformation. A descriptive analysis of the data was then performed to evaluate the following information: the number of observations for each gas; the minimum and maximum values; the percentiles; the median; the standard deviation (σ^2); and the coefficient of variation (*CV*). The *CV* can be used to compare the variability within populations, showing whether the dataset is homogeneous or heterogeneous. According to Gotelli & Ellison (2010), $CV \leq 15\%$ indicates low dispersion and therefore homogeneity; $15\% \leq CV \leq 30\%$ indicates medium dispersion; and $CV \geq 30\%$ indicates high dispersion and therefore heterogeneity. Finally, the Mann-Whitney test was used to compare the gas fluxes in both wetland types. Due to the high heterogeneity in measurement methods, environmental conditions, wetland designs and reported variables across studies, a formal meta-analysis was not considered appropriate. In several cases, flux values were reported without associated measures of dispersion or were obtained through figure digitization, which further limited the possibility of calculating standardized effect sizes.

Restricting the analysis only to studies reporting variance would substantially reduce the dataset and compromise its global representativeness. Therefore, non-parametric statistical comparisons were applied to evaluate differences between wetland types. This approach allows a descriptive comparison of reported fluxes but does not aim to identify causal drivers of variability among studies.

RESULTS AND DISCUSSION

The number of observations differed among gases and wetland types because not all selected studies reported CH_4, CO_2 and N_2O simultaneously, and the availability of eligible data varied across the literature. In addition, some studies evaluated only natural wetlands or only constructed wetlands, which resulted in different sample sizes for each gas and wetland type in Figs 2–4.

The median emissions were evaluated, and a significant difference was observed between the systems: The methane concentrations in natural and constructed wetlands were found to be 1.25 mg CH_4 m^{-2} h^{-1} (*IQR*: 0.06–6.96) and 6.46 mg CH_4 m^{-2} h^{-1} (*IQR*: 0.15–17.59) respectively (Fig. 2). Constructed wetlands exhibited a 517% increase in CH_4 flux compared to natural wetlands, and this difference was statistically significant. The wider dispersion observed in constructed wetlands reflects the presence of extreme values in the dataset, particularly in comparison to natural wetlands.

The higher CH_4 emissions observed in constructed wetlands can be attributed to the influent wastewater treatment processes that occur within these systems. Mander et al. (2014a) and Zhao et al. (2016) conducted research into the relationship between total organic carbon (TOC) and emissions in constructed wetlands. Their findings indicated a positive correlation between the two variables, suggesting that the amount of carbon directly influences the emission of this gas. This phenomenon can be attributed to the attenuation of OM load in constructed wetlands through a combination of physical, chemical, and biological processes typical of these systems (López et al., 2015; Vymazal, 2007). The higher availability of organic carbon derived from wastewater provides a greater substrate for microbial degradation and methanogenesis under anaerobic conditions, which can enhance CH_4 production (Bastviken, 2009; Li et al., 2019).

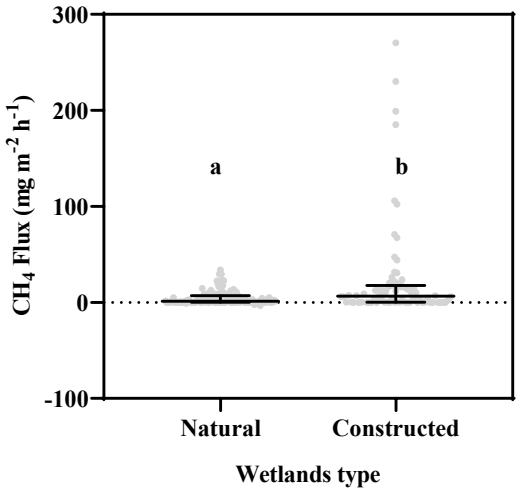


Figure 2. Comparison of median CH_4 fluxes in natural (n = 161) and constructed (n = 79) wetlands. The bars represent the medians, and the error bars were calculated within the 25th to 75th percentile range. Different lowercase letters indicate statistically significant differences in CH_4 emissions between groups (Mann–Whitney test, $p < 0.05$).

The highest CH_4 emission values were reported by Wang et al. (2008), who compared CH_4 fluxes from different systems and examined the relationships between methane emissions, seasonal variation, and the characteristics of domestic sewage . The authors verified that the relationship between environmental factors and the activities of methanogens and methanotrophs varies between plant species. They also identified the growth state of the aquatic plant rhizosphere as an important parameter for CH_4 emission (Wang et al., 2008).

The lowest value (corresponding to the highest CH4 oxidation value) was identified in the study by Zhao et al. (2016). The objective of this study was to investigate and compare the effects of plant species richness and monoculture on CH_4 emission and nitrogen removal. The authors concluded that identity is associated with CH_4 emission and that *Phalaris arundinacea* monoculture (the study's lowest value) is capable of controlling CH4 emission (Zhao et al., 2016).

The median CO_2 emissions observed in natural wetlands were 137.90 mg CO_2 m^{-2} h^{-1} (0.00–320.20), and in constructed wetlands, 171.20 mg CO_2 m^{-2} h^{-1} (22.24–238.60). The Mann-Whitney test revealed no significant difference between these results (Fig. 3). The variability observed reflects the wide range of values reported across studies, particularly in constructed wetlands.

In the context of effluent treatment, OM is subject to decomposition by microorganisms, with the concomitant release of CO_2 through their metabolic pathways (Kong et al., 2023). Consequently, CO_2 emissions are directly associated with the carbon

entering the system. Despite the anticipated predominance of the OM present in an effluent over that found in water within natural ecosystems, no substantial disparities were identified between the areas examined. This phenomenon is likely attributable to the fact that CO_2 production occurs via two types of organisms, namely autotrophic and heterotrophic, and under oxic and anoxic conditions (Elberling et al., 2011; Nilsson & Öquist, 2013). Furthermore, the production of CO_2 in these systems is associated with the presence of other microbial communities, including those responsible for the complete degradation of OMthrough denitrification and the reduction of iron, manganese, and sulphate, among others, thereby increasing CO_2 production at the expense of CH_4 production. It has been established that microbial degradation processes, including acetoclastic methanogenesis, result in the production of carbon dioxide (Bastviken, 2009; Nilsson & Öquist, 2013).

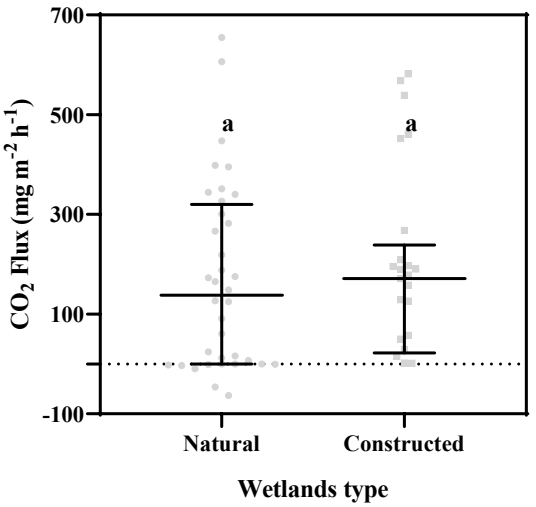


Figure 3. Comparison of median CO_2 emissions in natural (n = 36) and constructed (n = 25) wetlands. The bars represent the medians, and the error bars were calculated at the 25th to 75th percentile range. Different lowercase letters indicate statistically significant differences in CO_2 emissions between groups (Mann-Whitney test, $p < 0.05$). Some CO_2 consumption values for constructed wetlands were removed from the graph to improve visualisation of the medians.

The lowest CO_2 values were found to be associated with its consumption. The lowest values documented in the extant literature were reported by Wu et al. (2016). The authors of the study established that temperature and the presence of plants have a significant impact on net CO_2 exchange between constructed wetland systems and the atmosphere. The study was conducted in a cold climate location in China, and the plant species with the lowest emission value was *Zizania caduciflora*. This low flux was attributed to autotrophic respiration and photosynthesis, which increased the net CO_2 exchange.

The highest values of CO_2 emissions were found in a study by De la Varga et al. (2015). Although this was not discussed by the authors, the high CO_2 flux may be associated with the elevated organic carbon load in the influent wastewater, since influent carbon availability is an important driver of carbon emissions in constructed wetlands (Mander et al., 2014b; Wang et al., 2023).

Regarding N_2O fluxes, median values were higher in constructed wetlands than in natural wetlands. Natural wetlands presented a median flux of 0.00 mg N_2O m^{-2} h^{-1} (0.00–0.00), while constructed wetlands showed a median of 0.20 mg N_2O m^{-2} h^{-1} (0.06–0.54) (Fig. 4). This difference was statistically significant. The wider dispersion observed in constructed wetlands reflects the variability of nitrogen transformation processes across systems.

The emission of N_2O in constructed wetlands is associated with the nitrogen cycle in the context of effluent treatment. This nutrient is consumed by nitrifying and denitrifying bacteria. However, when environmental conditions are not optimal, incomplete nitrification or denitrification may occur, leading to the release of N_2O as an intermediate product (Zoppas et al., 2016).

In relation to N_2O emissions, the highest N_2O fluxes reported in the analysed literature were observed by Uggetti et al. (2012), who investigated constructed wetlands receiving activated sludge. These emissions were associated with oxygen availability during treatment, since nitrification occurs under aerobic conditions while denitrification occurs under anoxic conditions. When these processes are not fully coupled, N_2O may accumulate and be released as an intermediate product of the nitrogen cycle (Leverenz et al., 2009; Quick et al., 2019).

Conversely, the study with the lowest N_2O emission values reported for constructed wetlands were measured in systems treating tile drainage water. In these systems, drainage water collected from agricultural fields through tile drainage systems is directed to constructed wetlands, where nitrate removal occurs mainly through denitrification before the water is discharged downstream. In comparison to the maximum emission levels, the present study demonstrated that highlight the importance of nutrient load as a key factor influencing N_2O emissions in constructed wetlands. Furthermore, in this study, the authors found a relationship between nitrate removal and emission of this gas, with an average N_2O emission value of 2.3% in relation to the total nitrate removal (Groh et al., 2015).

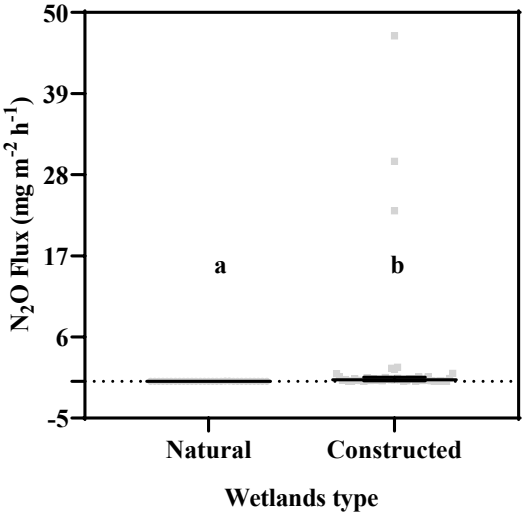


Figure 4. Comparison of median nitrous oxide (N_2O) emissions in natural (n = 29) and constructed (n = 45) wetlands. The bars represent the medians, and the error bars were calculated at the 25th to 75th percentile range. Different lowercase letters indicate statistically significant differences in N_2O emissions between groups (Mann–Whitney test, $p < 0.05$).

A high degree of data dispersion was observed within both natural and constructed wetlands for all gases, and it is hypothesised that this reflects the variability in environmental conditions between study sites, as well as differences in gas production and consumption processes.. Differences in environmental conditions among study sites may partially explain the variability observed in GHG fluxes. For example, variations in oxygen availability between sites may influence methanogenesis, which is favoured under anaerobic conditions and inhibited under oxic conditions (Bastviken, 2009; Olsson et al., 2015). Similarly, differences in plant species composition and physiological characteristics among wetlands may influence CO_2 fluxes through variations in

photosynthesis and plant respiration (Frolking et al., 1998; Moreno-Sotomayor et al., 2002; Snyder et al., 2009). In the case of N_2O, differences in nitrate and ammonium concentrations between sites may also contribute to the variability in emissions (Baulch et al., 2011).

For all gases under investigation, it is also pertinent to observe the *C/N* ratios of the influent wastewater may also influence GHG fluxes, as variations in OM microbial processes in wetlands. Although this parameter was not directly evaluated in the present dataset, previous studies have shown that *C/N* ratios can influence both nutrient removal efficiency and GHG emissions. For example,Yan et al. (2012) investigated the *C/N* ratios of synthetic municipal waters with regard to CO_2 and CH_4 emissions. The researchers concluded that the optimal *C/N* ratio to achieve the best efficiency in simultaneous biological nutrient removal and the lowest gas emission is *C/N* = 5:1. Similarly, Li et al. (2017) conducted a study on the correlation between *C/N* ratios and nitrogen removal processes, as well as N_2O emissions. Their findings indicated that a *C/N* ratio of 12:1 yielded optimal nitrogen removal efficiency while concurrently maintaining minimal N_2O emissions. This findings suggestthat the quality of the influentmay influence both treatment performance and GHG emissions. It is therefore concluded that, with effective control measures in place, it is possible to achieve optimal removal conditions while maintaining low GHG emissions.

The results obtained in this study suggest that the design and operational conditions of constructed wetlands may influence GHG emissions. Factors such as hydraulic regime, oxygen availability, and organic and nutrient loads can affect the balance between microbial processes responsible for CH_4, CO_2, and N_2O production and consumption. Previous studies have shown that parameters such as wetland configuration, vegetation type, and hydraulic conditions can significantly influence greenhouse gas fluxes in these systems (Mander et al., 2014; Vymazal, 2007; Guo et al., 2020). Therefore, optimising these parameters during the design and operation of constructed wetlands may help minimise GHG emissions while maintaining efficient wastewater treatment performance.

This study has some limitations that should be acknowledged. The compiled dataset was derived from studies with heterogeneous wetland designs, environmental conditions, influent characteristics and measurement methods. In addition, not all studies reported the same set of environmental variables, and when reported, these variables were often available for only a limited number of observations. This resulted in insufficient data to support statistically robust correlation analyses between GHG fluxes and potential explanatory variables. Consequently, the analysis was restricted to a descriptive comparison of reported fluxes between natural and constructed wetlands, and the discussion of potential drivers was based on mechanisms reported in the literature rather than on direct statistical associations.

CONCLUSIONS

This integrative assessment of greenhouse gas (GHG) fluxes (CH_4, CO_2 and N_2O) in natural and constructed wetlands revealed differences in gas emissions between natural and constructed wetland systems. No significant differences in CO_2 emissions were observed in constructed wetlands compared to natural wetlands, possibly reflecting

the widespread microbial processes responsible for carbon mineralisation in both environments. However, significant differences in CH_4 and N_2O emissions were observed due to the stimulation of microbial processes by the nutrients present in the effluents. All gases in both types of wetland show high data dispersion related to changes in the production and consumption of gases in these environments. Overall, the findings emphasise the importance of considering both sewage treatment efficiency and GHG balance in the design and implementation of sustainable constructed wetlands.

ACKNOWLEDGEMENTS. This research was conducted without external financial support. The authors declare that no specific funding was received from public, commercial, or not-for-profit funding agencies.

REFERENCES

Balwan, W.K. & Kour, S. 2021. Wetland-An Ecological Boon for the Environment East African Scholars Journal of Agriculture and Life Sciences Wetland- An Ecological Boon for the Environment. *East African Scholars Journal of Agriculture and Life Sciences* **4**(3), 38–48. https://doi.org/10.13140/RG.2.2.15728.79368

Bastviken, D. 2009. Methane. *Encyclopedia of Inland Waters* **2**, 783–805. https://doi.org/10.1016/B978-012374410-4.00385-X

Bateganya, N.L., Mentler, A., Langergraber, G., Busulwa, H. & Hein, T. 2015. Carbon and nitrogen gaseous fluxes from subsurface flow wetland buffer strips at mesocosm scale in East Africa. *Ecological Engineering* **85**, 173–184. https://doi.org/10.1016/j.ecoleng.2015.09.081

Baulch, H.M., Schiff, S.L., Maranger, R. & Dillon, P.J. 2011. Nitrogen enrichment and the emission of nitrous oxide from streams. *Global Biogeochemical Cycles* **25**, GB4013. https://doi.org/10.1029/2011GB004047

Benbow, S. 2020. *Graph Grabber* 4.6. Quintessa Ltd.

Boratto, D.C., Barreto, A.B., Sezerino, P.H. & Souza, C.L. de. 2021. Wetlands construídos empregados no tratamento de esgoto sob o contexto do saneamento de baixo carbono. *Revista Ibero-Americana de Ciências Ambientais* **12**(7), 390–405. https://doi.org/10.6008/cbpc2179-6858.2021.007.0035

Chang, T.C. & Yang, S.S. 2003. Methane emission from wetlands in Taiwan. *Atmospheric Environment* **37**(32), 4551–4558. https://doi.org/10.1016/S1352-2310(03)00588-0

Chen, X., Zhu, H., Yan, B., Shutes, B., Xing, D., Banuelos, G., Cheng, R. & Wang, X. 2020. Greenhouse gas emissions and wastewater treatment performance by three plant species in subsurface flow constructed wetland mesocosms. *Chemosphere* **239**, 124795. https://doi.org/10.1016/j.chemosphere.2019.124795

Clair, T.A., Arp, P., Moore, T.R., Dalva, M. & Meng, F.-R. 2002. Gaseous carbon dioxide and methane, as well as dissolved organic carbon losses from a small temperate wetland under a changing climate. *Environmental Pollution* **116**(Suppl. 1), S143–S148. https://doi.org/10.1016/s0269-7491(01)00267-6

De la Varga, D., Ruiz, I., Álvarez, J.A. & Soto, M. 2015. Methane and carbon dioxide emissions from constructed wetlands receiving anaerobically pretreated sewage. *Science of the Total Environment* **538**, 824–833. https://doi.org/10.1016/j.scitotenv.2015.08.090

Elberling, B., Askaer, L., Jørgensen, C.J., Joensen, H.P., Kühl, M., Glud, R.N. & Lauritsen, F.R. 2011. Linking soil O_2, CO_2, and CH_4 concentrations in a wetland soil: Implications for CO_2 and CH_4 fluxes. *Environmental Science and Technology* **45**(8), 3393–3399. https://doi.org/10.1021/es103540k

EPA, U.S.E.P.A. 2022. Wetlands Restoration Definitions and Distinctions. https://www.epa.gov/wetlands/wetlands-restoration-definitions-and-distinctions

Frolking, S.E., Bubier, J.L., Moore, T.R., Ball, T., Bellisario, L.M., Bhardwaj, A., Carroll, P., Crill, P.M., Lafleur, P.M., McCaughey, J.H., Roulet, N.T., Suyker, A.E., Verma, S.B., Waddington, J.M. & Whiting, G.J. 1998. Relationship between ecosystem productivity and photosynthetically active radiation for northern peatlands. *Global Biogeochemical Cycles* **12**(1), 115–126. https://doi.org/10.1029/97GB03367

Fuchs, V.J., Mihelcic, J.R. & Gierke, J.S. 2011. Life cycle assessment of vertical and horizontal flow constructed wetlands for wastewater treatment considering nitrogen and carbon greenhouse gas emissions. *Water Research* **45**, 2073–2081. https://doi.org/10.1016/j.watres.2010.12.021

Gallant, K., Withey, P., Risk, D., van Kooten, G.C. & Spafford, L. 2020. Measurement and economic valuation of carbon sequestration in Nova Scotian wetlands. *Ecological Economics* **171**, 106619. https://doi.org/10.1016/j.ecolecon.2020.106619

Gleason, R.A., Tangen, B.A., Browne, B.A. & Euliss, N.H. 2009. Greenhouse gas flux from cropland and restored wetlands in the Prairie Pothole Region. *Soil Biology and Biochemistry* **41**(12), 2501–2507. https://doi.org/10.1016/j.soilbio.2009.09.008

Gotelli, N.J. & Ellison, A.M. 2010. *Princípios de Estatística em Ecologia*. 1st ed. Artmed.

Grinham, A., Albert, S., Deering, N., Dunbabin, M., Bastviken, D., Sherman, B., Lovelock, C.E. & Evans, C.D. 2018. The importance of small artificial water bodies as sources of methane emissions in Queensland, Australia. *Hydrology and Earth System Sciences* **22**(10), 5281–5298. https://doi.org/10.5194/hess-22-5281-2018

Groh, T.A., Gentry, L.E. & David, M.B. 2015. Nitrogen removal and greenhouse gas emissions from constructed wetlands receiving tile drainage water. *Journal of Environmental Quality* **44**(3), 1001–1010. https://doi.org/10.2134/jeq2014.10.0415

Guo, F., Zhang, J., Yang, X., He, Q., Ao, L. & Chen, Y. 2020. Impact of biochar on greenhouse gas emissions from constructed wetlands under various influent chemical oxygen demand to nitrogen ratios. *Bioresource Technology* **303**, 122908. https://doi.org/10.1016/j.biortech.2020.122908

Hernández, M.E., Galindo-Zetina, M. & Hernández-Hernández, J.C. 2018. Greenhouse gas emissions and pollutant removal in treatment wetlands with ornamental plants under subtropical conditions. *Ecological Engineering* **114**, 88–95. https://doi.org/10.1016/j.ecoleng.2017.06.001

Hirota, M., Tang, Y., Hu, Q., Hirata, S., Kato, T., Mo, W., Cao, G. & Mariko, S. 2004. Methane emissions from different vegetation zones in a Qinghai-Tibetan Plateau wetland. *Soil Biology and Biochemistry* **36**(5), 737–748. https://doi.org/10.1016/j.soilbio.2003.12.009

Ji, B., Chen, J., Mei, J., Chang, J., Li, X., Jia, W. & Qu, Y. 2020. Roles of biochar media and oxygen supply strategies in treatment performance, greenhouse gas emissions, and bacterial community features of subsurface-flow constructed wetlands. *Bioresource Technology* **302**, 122890. https://doi.org/10.1016/j.biortech.2020.122890

Jordan, S., Strömgren, M., Fiedler, J., Lundin, L., Lode, E. & Nilsson, T. 2016. Ecosystem respiration, methane and nitrous oxide fluxes from ecotopes in a rewetted extracted peatland in Sweden. *Mires and Peat* **17**, 1–23. https://doi.org/10.19189/MaP.2016.OMB.224

Jyoti Nath, R., Zaman, A.S.N., Sarmah, N., Sarmah, R., Bhagabati, S.K. & Dutta, R. 2022. Sediment organic carbon stock and carbon sequestration estimate of a tropical floodplain wetland in Assam, India. *Journal of Experimental Zoology India* **26**(1), 883–890. https://doi.org/10.51470/jez.2023.26.1.883

Kasak, K., Valach, A.C., Rey-Sanchez, C., Kill, K., Shortt, R., Liu, J., Dronova, I., Mander, Ü., Szutu, D., Verfaillie, J. & Baldocchi, D.D. 2020. Experimental harvesting of wetland plants to evaluate trade-offs between reducing methane emissions and removing nutrients accumulated to the biomass in constructed wetlands. *Science of the Total Environment* **715**, 136960. https://doi.org/10.1016/j.scitotenv.2020.136960

Kong, F., Wang, J., Hou, W., Cui, Y., Yu, L., Zhang, Y. & Wang, S. 2023. Influence of modified biochar supported sulfidation of nano-zero-valent-iron (S-nZVI/BC) on nitrate removal and greenhouse gas emission in constructed wetland. *Journal of Environmental Sciences* **125**, 568–581. https://doi.org/10.1016/j.jes.2022.02.040

Leverenz, H.L., Tchobanoglous, G. & Darby, J.L. 2009. Clogging in intermittently dosed sand filters used for wastewater treatment. *Water Research* **43**(3), 695–705. https://doi.org/10.1016/j.watres.2008.10.054

Li, M., Wu, H., Zhang, J., Ngo, H.H., Guo, W. & Kong, Q. 2017. Nitrogen removal and nitrous oxide emission in surface flow constructed wetlands for treating sewage treatment plant effluent: Effect of C/N ratios. *Bioresource Technology* **240**, 157–164. https://doi.org/10.1016/j.biortech.2017.02.054

Li, T., Li, H., Zhang, Q., Ma, Z., Yu, L., Lu, Y., Niu, Z., Sun, W. & Liu, J. 2019. Prediction of CH_4 emissions from potential natural wetlands on the Tibetan Plateau during the 21st century. *Science of the Total Environment* **657**, 498–508. https://doi.org/10.1016/j.scitotenv.2018.11.275

Liikanen, A., Huttunen, J.T., Karjalainen, S.M., Heikkinen, K., Väisänen, T.S., Nykänen, H. & Martikainen, P.J. 2006. Temporal and seasonal changes in greenhouse gas emissions from a constructed wetland purifying peat mining runoff waters. *Ecological Engineering* **26**(3), 241–251. https://doi.org/10.1016/j.ecoleng.2005.10.005

Liu, F., Zhang, Y., Liang, H. & Gao, D. 2019. Long-term harvesting of reeds affects greenhouse gas emissions and microbial functional genes in alkaline wetlands. *Water Research* **164**, 114936. https://doi.org/10.1016/j.watres.2019.114936

López, D., Fuenzalida, D., Vera, I., Rojas, K. & Vidal, G. 2015. Relationship between the removal of organic matter and the production of methane in subsurface flow constructed wetlands designed for wastewater treatment. *Ecological Engineering* **83**, 296–304. https://doi.org/10.1016/j.ecoleng.2015.06.037

Luo, B., Du, Y., Han, W., Geng, Y., Wang, Q., Duan, Y., Ren, Y., Liu, D., Chang, J. & Ge, Y. 2020. Reduce health damage cost of greenhouse gas and ammonia emissions by assembling plant diversity in floating constructed wetlands treating wastewater. *Journal of Cleaner Production* **244**, 118927. https://doi.org/10.1016/j.jclepro.2019.118927

Mander, Ü., Dotro, G., Ebie, Y., Towprayoon, S., Chiemchaisri, C., Nogueira, S.F., Jamsranjav, B., Kasak, K., Truu, J., Tournebize, J. & Mitsch, W.J. 2014a. Greenhouse gas emission in constructed wetlands for wastewater treatment: A review. *Ecological Engineering* **66**, 19–35. https://doi.org/10.1016/j.ecoleng.2013.12.006

Mander, Ü., Kuusemets, V., Lõhmus, K., Mauring, T., Teiter, S. & Augustin, J. 2003. Nitrous oxide, dinitrogen and methane emission in a subsurface flow constructed wetland. *Water Science and Technology* **48**(5), 135–142. https://doi.org/10.2166/wst.2003.0301

Mander, Ü., Lõhmus, K., Teiter, S., Mauring, T., Nurk, K. & Augustin, J. 2008. Gaseous fluxes in the nitrogen and carbon budgets of subsurface flow constructed wetlands. *Science of the Total Environment* **404**(2–3), 343–353. https://doi.org/10.1016/j.scitotenv.2008.03.014

Mander, Ü., Tournebize, J., Kasak, K. & Mitsch, W.J. 2014b. Climate regulation by free water surface constructed wetlands for wastewater treatment and created riverine wetlands. *Ecological Engineering* **72**, 103–115. https://doi.org/10.1016/j.ecoleng.2013.05.004

Mendonça, R., Müller, R.A., Clow, D., Verpoorter, C., Raymond, P., Tranvik, L.J. & Sobek, S. 2017. Organic carbon burial in global lakes and reservoirs. *Nature Communications* **8**, 1694. https://doi.org/10.1038/s41467-017-01789-6

Mitsch, W.J., Bernal, B., Nahlik, A.M., Mander, Ü., Zhang, L., Anderson, C.J., Jørgensen, S.E. & Brix, H. 2013. Wetlands, carbon, and climate change. *Landscape Ecology* **28**, 583–597. https://doi.org/10.1007/s10980-012-9758-8

Moreno-Sotomayor, A., Weiss, A., Paparozzi, E.T. & Arkebauer, T.J. 2002. Stability of leaf anatomy and light response curves of field grown maize as a function of age and nitrogen status. *Journal of Plant Physiology* **159**(8), 819–826. https://doi.org/10.1078/0176-1617-00809

Nilsson, M. & Öquist, M. 2013. Partitioning litter mass loss into carbon dioxide and methane in peatland ecosystems. *Geophysical Monograph Series* **184**, 131–144. https://doi.org/10.1029/2008GM000819

Ollivier, Q.R., Maher, D.T., Pitfield, C. & Macreadie, P.I. 2019. Punching above their weight: Large release of greenhouse gases from small agricultural dams. *Global Change Biology* **25**(2), 721–732. https://doi.org/10.1111/gcb.14477

Olsson, L., Ye, S., Yu, X., Wei, M., Krauss, K.W. & Brix, H. 2015. Factors influencing CO_2 and CH_4 emissions from coastal wetlands in the Liaohe Delta, Northeast China. *Biogeosciences* **12**(16), 4965–4977. https://doi.org/10.5194/bg-12-4965-2015

Quick, A.M., Reeder, W.J., Farrell, T.B., Tonina, D., Feris, K.P. & Benner, S.G. 2019. Nitrous oxide from streams and rivers: A review of primary biogeochemical pathways and environmental variables. *Earth-Science Reviews* **191**, 224–262. https://doi.org/10.1016/j.earscirev.2019.02.021

Ramsar Convention Secretariat. 2013. *The Ramsar Convention Manual: A Guide to the Convention on Wetlands*. 6th ed. Ramsar Convention Secretariat.

Rychlik, S. & Dąbrowska-Zielińska, K. 2011. Chamber measurements of CO_2 exchange in different wetland sites in Biebrza National Park, Poland. *Journal of Water and Land Development* **15**(1), 179–182. https://doi.org/10.2478/v10025-012-0016-x

Silva, J.P. 2016. Greenhouse gas emissions from a pilot-scale small decentralized sewage treatment: anaerobic filter + constructed wetland. *Ingeniería y Competitividad* **18**(2), 101–112.

Singh, S.N., Kulshreshtha, K. & Agnihotri, S. 2000. Seasonal dynamics of methane emission from wetlands. *Chemosphere: Global Change Science* **2**, 39–46.

Snyder, C.S., Bruulsema, T.W., Jensen, T.L. & Fixen, P.E. 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agriculture, Ecosystems and Environment* **133**, 247–266. https://doi.org/10.1016/j.agee.2009.04.021

Stefanakis, A., Akratos, C.S. & Tsihrintzis, V.A. 2014. Constructed wetlands classification. *Vertical Flow Constructed Wetlands*, 17–25. https://doi.org/10.1016/b978-0-12-404612-2.00002-7

Uggetti, E., García, J., Lind, S.E., Martikainen, P.J. & Ferrer, I. 2012. Quantification of greenhouse gas emissions from sludge treatment wetlands. *Water Research* **46**(6), 1755–1762. https://doi.org/10.1016/j.watres.2011.12.049

VanderZaag, A.C., Gordon, R.J., Burton, D.L., Jamieson, R.C. & Stratton, G.W. 2010. Greenhouse gas emissions from surface flow and subsurface flow constructed wetlands treating dairy wastewater. *Journal of Environmental Quality* **39**(2), 460–471. https://doi.org/10.2134/jeq2009.0166

Vymazal, J. 2007. Removal of nutrients in various types of constructed wetlands. *Science of the Total Environment* **380**(1–3), 48–65. https://doi.org/10.1016/j.scitotenv.2006.09.014

Vymazal, J., Greenway, M., Tonderski, K., Brix, H. & Mander, Ü. 2006. Constructed wetlands for wastewater treatment. In Verhoeven, J.T.A., Beltman, B., Bobbink, R., Whigham, D.F. eds. *Wetlands and Natural Resource Management*. Ecological Studies **190**, 69–96. Springer, Berlin, Heidelberg. https://doi.org/10.1016/B978-0-12-409548-9.11238-2

Wallace, S.D. & Knight, R.L. 2006. *Small-Scale Constructed Wetlands Treatment Systems: Feasibility, Design Criteria, and O&M Requirements*. IWA Publishing.

Wang, S., Li, X., Ji, M., Zhang, J., Tanveer, M. & Hu, Z. 2023. Is constructed wetlands carbon source or carbon sink? Case analysis based on life cycle carbon emission accounting. *Bioresource Technology* **388**, 129777. https://doi.org/10.1016/j.biortech.2023.129777

Wang, Y., Inamori, R., Kong, H., Xu, K., Inamori, Y., Kondo, T. & Zhang, J. 2008. Nitrous oxide emission from polyculture constructed wetlands: Effect of plant species. *Environmental Pollution* **152**(2), 351–360. https://doi.org/10.1016/j.envpol.2007.06.017

Whiting, G.J. & Chanton, J.P. 1993. Primary production control of methane emission from wetlands. *Nature* **364**(6440), 794–795. https://doi.org/10.1038/364794a0

Wu, H., Lin, L., Zhang, J., Guo, W., Liang, S. & Liu, H. 2016. Purification ability and carbon dioxide flux from surface flow constructed wetlands treating sewage treatment plant effluent. *Bioresource Technology* **219**, 768–772. https://doi.org/10.1016/j.biortech.2016.08.030

Wu, H., Zhang, J., Ngo, H.H., Guo, W., Hu, Z., Liang, S., Fan, J. & Liu, H. 2015. A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation. *Bioresource Technology* **175**, 594–601. https://doi.org/10.1016/j.biortech.2014.10.068

Yan, C., Zhang, H., Li, B., Wang, D., Zhao, Y. & Zheng, Z. 2012. Effects of influent C/N ratios on CO_2 and CH_4 emissions from vertical subsurface flow constructed wetlands treating synthetic municipal wastewater. *Journal of Hazardous Materials* **203–204**, 188–194. https://doi.org/10.1016/j.jhazmat.2011.12.002

Yu, X., Geng, Y., Heck, P. & Xue, B. 2015. A review of China's rural water management. *Sustainability* **7**(5), 5773–5792. https://doi.org/10.3390/su7055773

Zhao, Z., Chang, J., Han, W., Wang, M., Ma, D., Du, Y., Qu, Z., Chang, S.X. & Ge, Y. 2016. Effects of plant diversity and sand particle size on methane emission and nitrogen removal in microcosms of constructed wetlands. *Ecological Engineering* **95**, 390–398. https://doi.org/10.1016/j.ecoleng.2016.06.047

Zoppas, F.M., Bernardes, A.M. & Meneguzzi, Á. 2016. Operating parameters on biological nitrogen removal of water by simultaneous nitrification and denitrification. *Engenharia Sanitaria e Ambiental* **21**(1), 29–42 (in Portuguese). https://doi.org/10.1590/S1413-41520201600100134682

Supplementary_Table_S1

Study	Journal	Country	Wetlands type	Gases measured	Influent type	Macrophyte	Soil type
Audet et al., 2013	Ecological Engineering	Denmark	Natural	CH_4	Not Applicable	Agrostis stolonifera	Sand
Audet et al., 2013	Ecological Engineering	Denmark	Natural	CH_4	Not Applicable	Agrostis stolonifera	Mineral Soil
Audet et al., 2013	Ecological Engineering	Denmark	Natural	CH_4	Not Applicable	Trifolium repens	Sand
Audet et al., 2013	Ecological Indicators	Denmark	Natural	CH_4	Not Applicable	Equisetum fluviatile	Peatland
Barbera et al., 2014	Ecological Engineering	Italy	Constructed	CO_2	Domestic	Phragmites australis	Volcanic Gravel
Barbera et al., 2014	Environmental Science and Pollution Research	Italy	Constructed	CH_4, CO_2	Domestic	Chrysopogon zizanioides	Volcanic Gravel
Barbera et al., 2014	Environmental Science and Pollution Research	Italy	Constructed	CH_4, CO_2	Domestic	Cyperus papyrus	Volcanic Gravel
Barbera et al., 2014	Environmental Science and Pollution Research	Italy	Constructed	CH_4, CO_2	Domestic	Mischantus × giganteus	Volcanic Gravel
Bresney, 2015	Northeastern Naturalist	U.S.A.	Natural	CH_4, CO_2	Not Applicable	Elocharis obtusa Willd	Gravel
Bubier, et al., 1993	Wiley	Canada	Natural	CH_4	Not Applicable	Carex aquatilis	Clayish
Bubier, et al., 1993	Wiley	Canada	Natural	CH_4	Not Applicable	Sphagnum fuscum	Clayish
Bubier, et al., 1993	Wiley	Canada	Natural	CH_4	Not Applicable	Sphagnum magellanicum	Clayish
Carballeira et al., 2017	Ecological Engineering	Spain	Constructed	CH_4, CO_2	Not reported	Iris pseudacorus	Gravel
Carballeira et al., 2017	Ecological Engineering	Spain	Constructed	CH_4, CO_2	Not reported	Juncus effuses	Gravel
Carballeira et al., 2017	Ecological Engineering	Spain	Constructed	CH_4, CO_2	Not reported	Phragmites australis	Gravel
Carballeira et al., 2017	Ecological Engineering	Spain	Constructed	CH_4, CO_2	Not reported	Typha latifolia	Gravel
Chang, et al., 2003	Atmospheric Environment	Taiwan	Natural	CH_4	Not Applicable	Kandelia candel	Clay Loam
Chang, et al., 2003	Atmospheric Environment	Taiwan	Natural	CH_4	Not Applicable	Phragmites communis	Sandy Loam
Chen, 2010	Water Air Soil Pollut	China	Natural	CH_4	Not Applicable	Carex muliensis	Not reported
Chen, 2010	Water Air Soil Pollut	China	Natural	CH_4	Not Applicable	Kobresia tibetica	Not reported
Chen, 2010	Water Air Soil Pollut	China	Natural	CH_4	Not Applicable	Polygonum amphibium	Not reported
Chen et al., 2009	Science of the Total Environment	China	Natural	CH_4	Not Applicable	Carex muliensis	Peatland
Chen et al., 2009	Science of the Total Environment	China	Natural	CH_4	Not Applicable	Elocharis valleculosa	Peatland
Chen, 2008	Journal of Geophysical Research	China	Natural	CH_4	Not Applicable	Carex muliensis	Not reported
Chen, 2008	Journal of Geophysical Research	China	Natural	CH_4	Not Applicable	Elocharis valleculosa	Not reported
Chen, 2009	Polish Journal of Ecology	China	Natural	CH_4	Not Applicable	Carex muliensis	Not reported
Chen, 2009	Polish Journal of Ecology	China	Natural	CH_4	Not Applicable	Elocharis valleculosa	Not reported
Chen, 2009	Environ Monit Assess	China	Natural	CH_4	Not Applicable	Carex muliensis e Eleocharis valleculosa	Not reported
Chen, 2017	Ecological Engineering	China	Natural	CH_4, CO_2, N_2O	Not Applicable	Kobresia tibetica	Not reported

Table S1 (continued)

Chen, 2020	Chemical Engineering Journal	China	Constructed	CH_4, CO_2, N_2O	Synthetic	Canna indica	Gravel and Biochar
Chen, 2020	Chemical Engineering Journal	China	Constructed	CH_4, CO_2, N_2O	Synthetic	Canna indica	Gravel
Chuersuwan et al., 2014	Songklanakarin Journal of Science and Technology	Thailand	Constructed	CH_4, CO_2, N_2O	Synthetic	Cyperus spp,	Not reported
Clair et al., 2002	Environmental Pollution	Canada	Natural	CH_4, CO_2	Not Applicable	Sphagnum centtale	Not reported
Cooper, 2017	Nature Climate Change	Canada	Natural	CH_4	Not Applicable	Carex rostrata	Peatland
Cooper, 2017	Nature Climate Change	Canada	Natural	CH_4	Not Applicable	Sphagnum	Peatland
Corbella et al., 2015	Ecological Engineering	Spain	Constructed	CH_4	Domestic	Phragmites australis	Not reported
Corradi, 2005	Global Change Biology	Russia	Natural	CH_4	Not Applicable	Carex appendiculata	Permafrost
Corradi, 2005	Global Change Biology	Russia	Natural	CH_4	Not Applicable	Eriophorum angustifolium	Permafrost
Dalva, 2001	Journal of Geophysical Research	Canada	Natural	CH_4, CO_2	Not Applicable	Sphagnum centtale	Not reported
De Klein et al., 2014	Ecological Engineering	Netherlands	Constructed	CH_4	Not reported	Phragmites	Sand
De la Varga et. al., 2015	Science of the Total Environment	Spain	Constructed	CH_4, CO_2	Not Applicable	Juncus effuses	Gravel
Devol et al., 1988	Journal of Geophysical Research	Brazil	Natural	CH_4, CO_2	Not reported	Paspalum repens	Not reported
Ding et al., 2005	Biology and Fertility of Soils	China	Natural	CH_4	Not Applicable	Carex lasiocarpa	Gley
Elberling et al., 2011	Environmental Science and Technology	Denmark	Natural	CH_4, CO_2	Not Applicable	Phalaris arundinacea	Peatland
Fey et al., 1999	Biology and Fertility of Soils	Germany	Constructed	N_2O	Agroindustrial	Phragmites australis	Sandy clay and peat
Franchini, 2014	Wetlands Ecol Manage	Swiss	Natural	CH_4	Not Applicable	Carex Nigras	Siliceous
Franchini, 2014	Wetlands Ecol Manage	Swiss	Natural	CH_4	Not Applicable	Carex rostrata	Calcareous
Franchini, 2015	FEMS Microbiology Ecology	Swiss	Natural	CH_4	Not Applicable	Carex rostrata	Not reported
Frenzel et al., 2000	Biogeochemistry	Estonia	Natural	CH_4	Not Applicable	Eriophorum	Peatland
Frenzel et al., 2000	Biogeochemistry	Estonia	Natural	CH_4	Not Applicable	Sphagnum	Peatland
Frenzel et al., 2000	Biogeochemistry	Estonia	Natural	CH_4	Not Applicable	Sphagnum cuspidatum	Peatland
Frenzel et al., 2000	Biogeochemistry	Estonia	Natural	CH_4	Not Applicable	Zygogonium ericetorum	Not reported
Fritzs, 2011	New Phytologist	Patagonia	Natural	CH_4	Not Applicable	Sphagnum	Not reported
Grand et al., 2010	Pacific Science	U.S.A.	Natural	CH_4	Not Applicable	Commelina diffusa	Volcanic soil
Groh et al., 2015	Journal of Environmental Quality	U.S.A.	Constructed	CH_4, CO_2, N_2O	Domestic	Phalaris arundinacea	Not reported
Henneberger, 2015	Wetlands	Swiss	Natural	CH_4, CO_2	Not Applicable	Carex rostrata	Siliceous
Heyer et al., 2002	Tellus. Series B: Chemical and Physical Meteorology	Russia	Natural	CH_4	Not Applicable	Carex spec	Peatland
Heyer et al., 2002	Tellus. Series B: Chemical and Physical Meteorology	Russia	Natural	CH_4	Not Applicable	Eriophorum vaginatum	Peatland
Heyer et al., 2002	Tellus. Series B: Chemical and Physical Meteorology	Russia	Natural	CH_4	Not Applicable	Ledum palustre	Peatland
Heyer et al., 2002	Tellus. Series B: Chemical and Physical Meteorology	Russia	Natural	CH_4	Not Applicable	Polytrichum spec,	Peatland

Table S1 (continued)

Heyer et al., 2002	Tellus. Series B: Chemical and Physical Meteorology	Russia	Natural	CH_4	Not Applicable	Sphagnum ssp,	Peatland
Hirota et al., 2004	Soil Biology and Biochemistry	China	Natural	CH_4	Not Applicable	Carex allivescers	Not reported
Hirota et al., 2004	Soil Biology and Biochemistry	China	Natural	CH_4	Not Applicable	Hippuris vulgaris L	Not reported
Hirota et al., 2004	Soil Biology and Biochemistry	China	Natural	CH_4	Not Applicable	Potamogeton pectinatus L,	Not reported
Hirota et al., 2004	Soil Biology and Biochemistry	China	Natural	CH_4	Not Applicable	Scirpus distigmaticus L,	Not reported
Hu, 2016	Plant Soil	China	Natural	CH_4, N_2O	Not Applicable	Carex cinerascens	Not reported
Inamori et al., 2007	Process Biochemistry	Japan	Constructed	CH_4, N_2O	Synthetic	Phragmites australis	Gravel and Sand
Inamori et al., 2007	Process Biochemistry	Japan	Constructed	CH_4, N_2O	Synthetic	Zizania latifolia	Gravel and Sand
Jia et al., 2011	Ecological Engineering	China	Constructed	N_2O	Synthetic	Phragmites australis	Gravel and Sand
Johansson et al., 2003	Tellus	Sweden	Constructed	N_2O	Domestic	Glyceria maxima Hartm	Not reported
Johansson et al., 2003	Tellus	Sweden	Constructed	N_2O	Domestic	Typha latifolia	Not reported
Johansson et al., 2004	Water Research	Sweden	Constructed	CH_4	Domestic	Glyceria maxima Hartm	Not reported
Johansson et al., 2004	Water Research	Sweden	Constructed	CH_4	Domestic	Typha latifolia	Not reported
Kang et al., 2002	Water. Air. and Soil Pollution	England	Natural	CH_4	Not Applicable	Sphagnum ssp,	Peatland
Kasak et al., 2020	Science of the Total Environment	Estonia	Constructed	CH_4	Agroindustrial	Typha latifolia	Not reported
Kasak et al., 2020	Science of the Total Environment	U.S.A.	Constructed	CH_4	Agroindustrial	Schoenoplectus acutus	Not reported
Li et al., 2017	Bioresource Technology	China	Constructed	N_2O	Synthetic	Phragmites australis	Sand
Liengaard et al., 2012	Frontiers in Microbiology	Brazil	Natural	N_2O	Not Applicable	Eichhornia crassipes	Not reported
Liu et al., 2009	Frontiers of Environmental Science and Engineering in China		Constructed	CH_4, N_2O	Domestic	Phragmites australis	Gravel and Sand
Liu et al., 2018	Environmental Science and Pollution Research	China	Constructed	CH_4	Domestic	Cyperus alternifolius	Gravel
Liu, 2015	Atmospheric Environment	China	Natural	CH_4, CO_2	Not Applicable	Carex meyeriana	Not reported
Maucieri et al., 2014	Italian Journal of Agronomy	Italy	Constructed	CH_4, CO_2	Not reported	Arundo donax L,	Volcanic Gravel
Maucieri et al., 2014	Italian Journal of Agronomy	Italy	Constructed	CH_4, CO_2	Not reported	Phragmites australis	Volcanic Gravel
McNamara, 2008	Science of the Total Environment	England	Natural	CH_4, CO_2	Not Applicable	Carex vulgaris	Peatland
McNamara, 2008	Science of the Total Environment	England	Natural	CH_4, CO_2	Not Applicable	Eriophorum spp	Peatland
McNamara, 2008	Science of the Total Environment	England	Natural	CH_4, CO_2	Not Applicable	Sphagnum ssp,	Peatland
Miao, 2012	Biogeosciences	China	Natural	CH_4	Not Applicable	Eriophorum vaginatum	Peatland
Miao, 2012	Biogeosciences	China	Natural	CH_4	Not Applicable	Sphagnum	Peatland
Öquist et al., 2002	Journal of Geophysical Research Atmospheres	Sweden	Natural	CH_4, CO_2	Not Applicable	Eriophorum angustifolium	Peatland
Öquist et al., 2002	Journal of Geophysical Research Atmospheres	Sweden	Natural	CH_4, CO_2	Not Applicable	Eriophorum vaginatum	Peatland
Pei-dong et al., 2002	Journal of Environmental Science	China	Constructed	CH_4, N_2O	Domestic	Phragmites australis	Not reported

Table S1 (continued)

Rask et al., 2002	Soil Biology and Biochemistry	Canada	Natural	CH_4	Not Applicable	Carex	Peatland
Ren, 2020	Atmosphere	China	Natural	CH_4	Not Applicable	Carex brevicuspis	Not reported
Ren, 2020	Atmosphere	China	Natural	CH_4	Not Applicable	Miscanthus sacchariflorus	Not reported
Roulet et al., 1993	Global Biogeochemical Cycles	Canada	Natural	CH_4	Not Applicable	Pleurozium shreberi	Not reported
Roulet et al., 1993	Global Biogeochemical Cycles	Canada	Natural	CH_4	Not Applicable	Sphagnum angustifolium	Not reported
Roulet et al., 1993	Global Biogeochemical Cycles	Canada	Natural	CH_4	Not Applicable	Sphagnum fuscum	Not reported
Roulet et al., 1993	Global Biogeochemical Cycles	Canada	Natural	CH_4	Not Applicable	Sphagnum russowii	Not reported
Roulet et al., 1993	Global Biogeochemical Cycles	Canada	Natural	CH_4	Not Applicable	Warnstorfia exannulata	Not reported
Rychlik et,al., 2011	Journal of Water and Land Development	Poland	Natural	CO_2	Not Applicable	Stellaria graminea L,	Peatland
Scott et al., 1999	Biogeochemistry	Canada	Natural	CH_4	Not Applicable	Sphagnum	Peatland
Song et al., 2012	Atmospheric Environment	China	Natural	CH_4	Not Applicable	Deyeucia angustifolia	Inceptisol
Song, 2003	Chinese Geographical Science	China	Natural	CH_4	Not Applicable	Carex	Peatland
Ström, 2007	Soil Biology & Biochemistry	Sweden	Natural	CH_4, CO_2	Not Applicable	Carex rotundata	Gelic Histosol
Ström, 2007	Soil Biology & Biochemistry	Sweden	Natural	CH_4, CO_2	Not Applicable	Eriophorum angustifolium	Gelic Histosol
Ström, 2007	Soil Biology & Biochemistry	Sweden	Natural	CH_4, CO_2	Not Applicable	Eriophorum vaginatum	Gelic Histosol
Uggetti et al., 2012	Water Research	Spain	Constructed	CH_4, N_2O	Not reported	Phragmites australis	Not reported
Wan, 2010	Remote Sensing of the Coastal Ocean. Land. and Atmosphere Environment	China	Natural	CH_4, CO_2	Not Applicable	Carex	Not reported
Wan, 2010	Remote Sensing of the Coastal Ocean. Land. and Atmosphere Environment	China	Natural	CH_4, CO_2	Not Applicable	Phragmites	Not reported
Wang et al., 2008	Ecological Engineering	Japan	Constructed	CH_4	Synthetic	Phragmites australis	Gravel and Sand
Wang et al., 2008	Ecological Engineering	Japan	Constructed	CH_4	Synthetic	Typha latifolia	Gravel and Sand
Wang et al., 2008	Ecological Engineering	Japan	Constructed	CH_4	Synthetic	Zizania latifolia	Gravel and Sand
Wang et al., 2008	Environmental Pollution	Japan	Constructed	N_2O	Domestic	Phragmites australis	Gravel and Sand
Wang et al., 2013	Environmental Pollution	China	Constructed	CH_4	Domestic	Zizania latifolia	Gravel and Sand
Whiting et al., 2001	Tellus. Series B: Chemical and Physical Meteorology	Canada	Natural	CH_4, CO_2	Not Applicable	Carex	Peatland
Whiting et al., 2001	Tellus. Series B: Chemical and Physical Meteorology	U.S.A.	Natural	CH_4, CO_2	Not Applicable	Typha latifolia	Not reported
Wilson, 2017	J. Geophys. Res. Biogeosci.	Canada	Natural	CH_4, CO_2	Not Applicable	Carex aquatilis	Not reported
Wilson, 2017	J. Geophys. Res. Biogeosci.	Canada	Natural	CH_4, CO_2	Not Applicable	Sphagnum	Not reported
Wu et al., 2009	Bioresource Technology	China	Constructed	N_2O	Synthetic	Phragmites australis	Sand
Wu et al., 2017	Journal of Cleaner Production	China	Constructed	CH_4, N_2O	Synthetic	Cyperus rotundus	Sand
Wu et al., 2017	Journal of Cleaner Production	China	Constructed	CH_4, N_2O	Synthetic	Phragmites australis	Sand

Table S1 (continued)

Wu et al., 2017	Journal of Cleaner Production	China	Constructed	CH_4, N_2O	Synthetic	Zizania caduciflora	Sand
Wu et al., 2016	Bioresource Technology	China	Constructed	CO_2	Synthetic	Cyperus rotundus	Sand
Wu et al., 2016	Bioresource Technology	China	Constructed	CO_2	Synthetic	Phragmites australis	Sand
Wu et al., 2016	Bioresource Technology	China	Constructed	CO_2	Synthetic	Zizania caduciflora	Sand
Yang, et al., 2013	Soil Biology and Biochemistry	China	Natural	CH_4, CO_2, N_2O	Not Applicable	Deyeucia angustifolia	Gley
Yang et al., 2014	Soil Biology and Biochemistry	China	Natural	CH_4	Not Applicable	Carex muliensis	Not reported
Yu, 2007	Environmental Management	China	Natural	N_2O	Not Applicable	Deyeucia angustifolia	Gley
Yu, 2013	Environmental Pollution	China	Natural	CH_4, CO_2	Not Applicable	Carex pamirensis	Permafrost
Zhang, 2018	Environ Sci Pollut Res	China	Constructed	CH_4	Not reported	Arundo donax L,	Gravel and Sand
Zhang, 2018	Environ Sci Pollut Res	China	Constructed	CH_4	Not reported	Cyperus alternifolius	Gravel and Sand
Zhang, 2018	Environ Sci Pollut Res	China	Constructed	CH_4	Not reported	Iris pseudacorus	Gravel and Sand
Zhang, 2018	Environ Sci Pollut Res	China	Constructed	CH_4	Not reported	Thalia dealbata	Gravel and Sand
Zhang, 2018	Environ Sci Pollut Res	China	Constructed	CH_4	Not reported	Typha orientalis	Gravel and Sand
Zhang, 2018 (3)	Ecological Engineering	China	Constructed	CH_4	Domestic	Ceratophyllum demersum	Not reported
Zhang, 2018 (3)	Ecological Engineering	China	Constructed	CH_4	Domestic	Hydrilla verticillata	Not reported
Zhang, 2018 (3)	Ecological Engineering	China	Constructed	CH_4	Domestic	Myriophyllum spicatum	Not reported
Zhang, 2018 (3)	Ecological Engineering	China	Constructed	CH_4	Domestic	Potamogeton crispus	Not reported
Zhang, 2020	Front. Earth Sci.	China	Natural	CH_4, CO_2	Not Applicable	Carex mulinesis	Not reported
Zhao et al., 2016	Ecological Engineering	China	Constructed	CH_4	Synthetic	Juncus effuses	Sand
Zhao et al., 2016	Ecological Engineering	China	Constructed	CH_4	Synthetic	Oenanthe javanica	Sand
Zhao et al., 2016	Ecological Engineering	China	Constructed	CH_4	Synthetic	Phalaris arundinacea	Sand
Zhao et al., 2016	Ecological Engineering	China	Constructed	CH_4	Synthetic	Rumex japonicus	Sand
Zhou, 2016	J. For. Res.	China	Natural	CH_4	Not Applicable	Carex muliensis	Peatland
Zhou, 2016	J. For. Res.	China	Natural	CH_4	Not Applicable	Kobresia tibetica	Peatland
Zhou, 2016	J. For. Res.	China	Natural	CH_4	Not Applicable	Potamogeton pusillus	Peatland
Zhou, 2020	Soil. Use and Management	China	Natural	CH_4, CO_2	Not Applicable	Carex muliensis	Peatland
Zhou, 2020	Soil. Use and Management	China	Natural	CH_4, CO_2	Not Applicable	Kobresia humilis	Peatland
Zhou, 2020	Soil. Use and Management	China	Natural	CH_4, CO_2	Not Applicable	Kobresia tibetica	Peatland
Zhu et al., 2007	Journal of Environmental Management	Japan	Constructed	CH_4	Domestic	Phragmites communis	Sand
Zhu, 2014	Atmospheric Environment	China	Natural	CH_4	Not Applicable	Carex lasiocarpa	Peatland