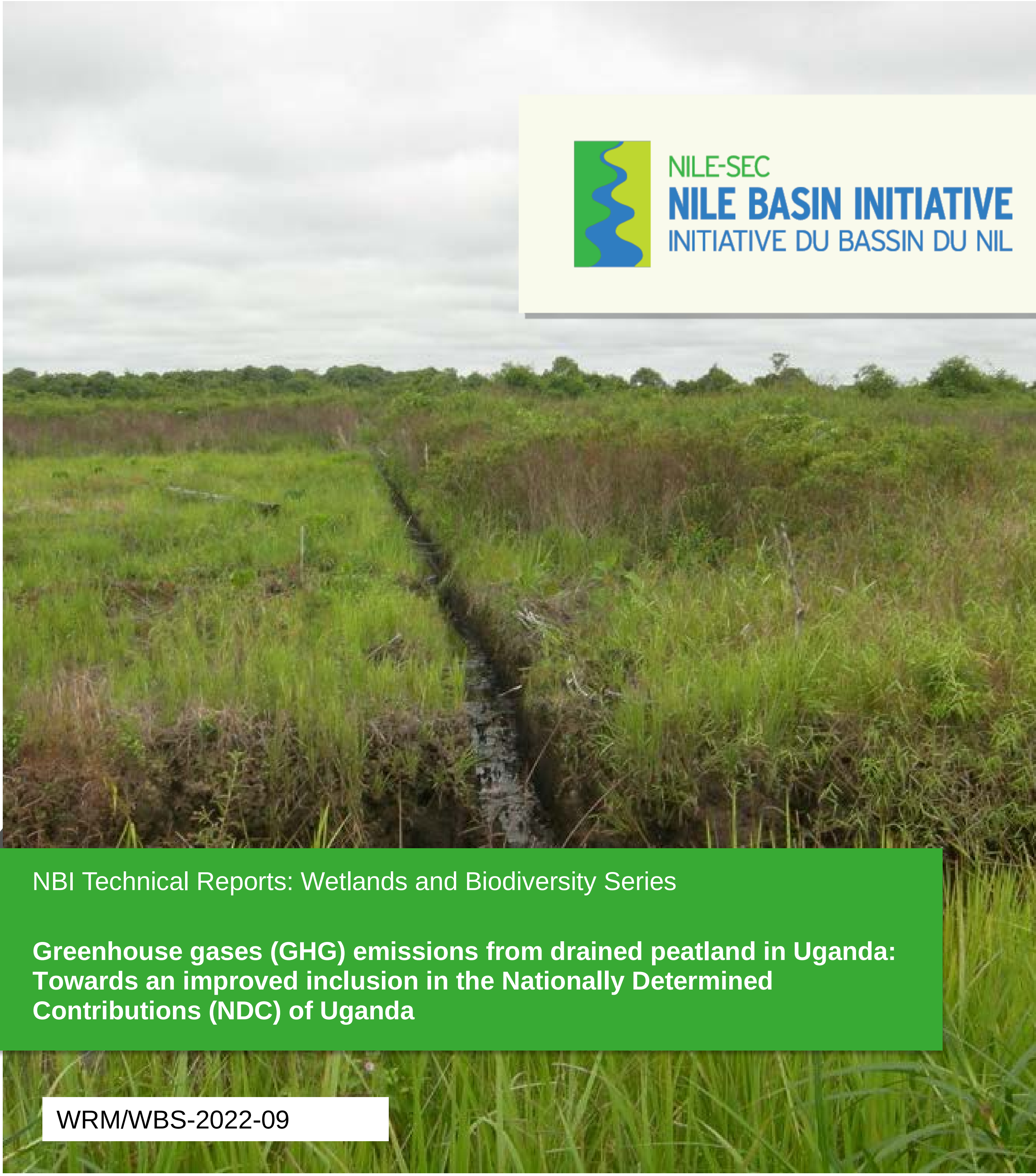

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NBI Technical Reports: Wetlands and Biodiversity Series

Greenhouse gases (GHG) emissions from drained peatland in Uganda: Towards an improved inclusion in the Nationally Determined Contributions (NDC) of Uganda

WRM/WBS-2022-09

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

Document Sheet

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The purpose of the technical report series is to support informed stakeholder dialogue and decision making in order to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the shared Nile Basin water resources.

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Contents

EXECUTIVE SUMMARY AND POLICY RECOMMENDATIONS

The project "Greenhouse gases (GHG) emissions from drained peatland in Uganda: Towards an improved inclusion in the Nationally Determined Contributions (NDC) of Uganda" is part of the grants of German Ministry for Environment (BMUV) awarded through *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)* International project: "DIAPOL-CE – Policy Dialogue on Low Emission Development: Political Dialogues for Climate Change and Peatland Management in the Nile Basin." It builds on the results of the study on CO_2 emissions avoidance potential from the Nile Basin peatlands and deducted policy recommendations, which was part of the baseline studies on the Nile wetlands and their ecosystem services, particularly in relation to climate change mitigation, and their integration in the river basin planning and climate policies (cf. Elshehawi et al., 2019a and b). The project aim is to stimulate the inclusion of mitigation activities to reduce greenhouse gas emissions (GHG) from drained peatlands in Uganda's climate policies, particularly its Nationally Determined Contributions (NDC) and stimulate such efforts in other NBI countries..

Monitoring, reporting and verification

The existing land cover products from Copernicus and CCI-ESA Africa are not suitable to base greenhouse gas estimates solely on land cover. Nevertheless, they provide necessary inputs for Tier 1[1] and possible future Tier 2[1] MRV systems as a cheap and quick way to calculate rough annual greenhouse gas emissions from drained peatlands. They may serve as a base map for investigation of the annual changes, where only Copernicus provides annual land cover products. Hence, Uganda will need to develop its own land cover for the peatland areas. This can be done by running own remote sensing classifications on annual basis, which may be expensive and technically challenging. Also, it will not compensate for the need for extensive ground-truthing campaigns.

Another option may be creating land cover maps through a hybrid remote sensing (using the existing products) and ground-truthing inventories at the district level every 3-5 years. For Tier 2 emissions estimates, specific greenhouse gas measurements, i.e. gas chambers or eddy covariance, need to be carried out for the different land cover types, which is so far nearly non-existent and would require expertise, time and money to develop. Alternative methods to calculate greenhouse gases like

[1] Tier 1 emission factors are given by IPCC for drained peatland as a uniform factor or differentiated factors per land use categories on organic soils, e.g. cropland and climate zone, e.g. tropical zone. Tier 2 emission factors are ones that are developed on national/regional basis using direct and/or indirect greenhouse gas emissions measurements specific for the national/regional situation.

water level monitoring and subsidence are cheaper and require less technical expertise. They may be suitable to develop in the short term, while emission specific for the different land covers are developed.

The land cover maps can be used in combination with water level monitoring and/or subsidence to prioritise areas that are hotspot for land use and/or drainage. Similarly, these land cover maps can be used to prioritise areas for rewetting and paludiculture in the near future. In conclusion, increased technical expertise through capacity building on the aspects of peatland mapping (including remote and on-site expertise), land cover and greenhouse emissions monitoring, reporting and verification are urgently needed to facilitate the inclusion of, and implementation, greenhouse emissions mitigation from drained peatlands in Uganda.

Collaborations with other Nile Basin countries may allow developing regional, instead of country, specific land cover maps and corresponding GHG emission factors. Such collaborations can be facilitated through the Nile Basin Initiative. This can be a mechanism to relieve the financial and technical burden of a single country, while stimulating transboundary management and collective restoration action. This may be particularly important since many of the large peatland basins within the Nile Basin are transboundary.

Paludiculture: value chains of papyrus under rewetting schemes.

Paludiculture livelihood options could be an essential part of peatland management strategies in NBI countries, specifically in Uganda, taking local communities dependent on land use options on board. It could make the rewetting of currently degraded peatlands suitable. Stakeholders reported that traditional and potential innovative uses constitute a pivotal alternative to unlock pioneering sustainable uses of peatland biomass as the supply of increasing high-quality biomass fibres and energy needs, while supporting climate smart livelihoods. Integrated paludiculture scheme connecting various value chains could enhance the potential for circular bio-economy by using discard material from fibre material use for energy purposes.

Studies and demonstration sites in other tropical regions like Southeast Asia and from temperate peatlands e.g. in Europe have highlighted the diverse innovative uses of biomass grown on rewetted peatlands in paludiculture. Focal peatland species like cattail (Typha spp.) and reed (Phragmites australis) are used for construction (roofing, boards, insulation), packaging and other high-quality materials, but also for renewable energy production, esp. for heat. Beside further development of profitable value chains and business cases, supportive agricultural policies in place and additional funding for establishment of production schemes along these chains are needed, e.g. to implement rewetting, adapted machineries, processing facilities, logistics.

A recent study commissioned by UN Environment stated that Uganda is among the eight countries for which funding support is especially urgent, others are Indonesia, Malaysia, Papua New Guinea, Brazil, Democratic Republic of Congo, Peru and Republic of Congo. Together, they could potentially account for 97 % of the carbon mitigation from tropical peatland investment. Multilateral donor schemes under the Article 6 of the Paris Agreement can be used to facilitate the funding. Carbon credits and carbon farming schemes, which are under development in Europe, can be secondary schemes to secure funding and create incentives for stakeholders.

The total potential yield of papyrus in Uganda is 4.7 million tonnes of dry weight assuming that all drained peatlands are rewetted and used for paludiculture. Nonetheless, further field validation is required to account for current drainage state, and crosschecking with papyrus' local productivity values.

INTRODUCTION

All Nile Basin countries are parties to the United Nations Framework Convention on Climate Change (UNFCCC) and adopted its Paris Agreement on Climate Change (PA). To achieve the objective of UNFCCC and PA, all Parties are obliged to communicate reliable, transparent and comprehensive information on GHG emissions, climate actions and support. All Nile Basin countries have submitted their first National Determined Contributions (NDC), South Sudan has already submitted an updated second NDC (South Sudan NDC, 2021). Only the Democratic Republic of Congo (DRC) has included specifical actions to mitigate the emissions from drained peatlands in their NDC (DRC NDC, 2021), despite their potential significance as part of the AFOLU sector for other Nile Basin countries, e.g. Uganda.

Uganda referred to "wetland restoration" as a mitigation activity for CO_2 emissions reduction in its first NDC in 2015 (Uganda INDC, 2015). The estimated emissions for the business as usual scenario until 2030 are 77.3 Mt CO_{2eq} annually. About 22 % of these emissions are from the LULUCF sector. Wetlands restoration as a reduction activity from the business as usual scenario by 2030 amounts to about 0.8 Mt CO_{2eq} (Figure 3). This activity, however, did not include emissions from drained peatlands (Uganda INDC, 2015).

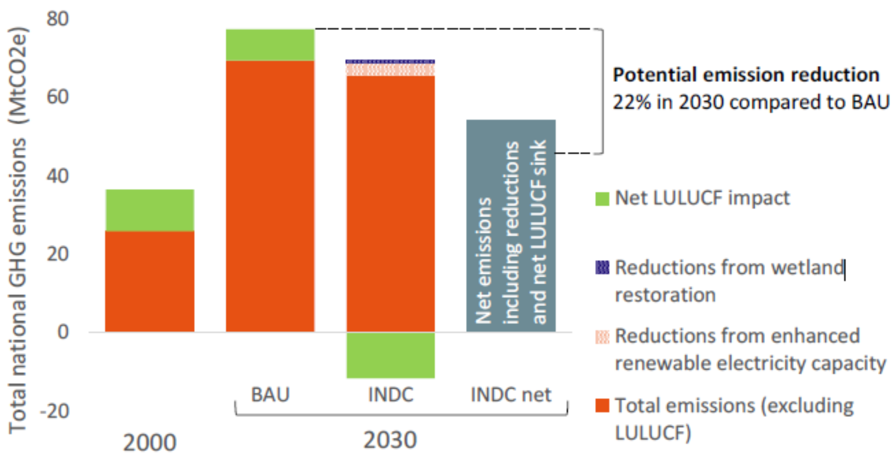


Figure 3. Illustration of emissions and reduction activities from Uganda INDC 2015 (source: Uganda INDC 2015).

The data in our work show that peatlands drainage, which cover less than 25 % of all the wetlands in Uganda, lead to GHG emissions of about 8 Mt CO_{2eq} annually from 2015 to 2035 in a business as usual scenario (Figure 4), which equals 10 % of the total annual national emissions by 2030 (Elshehawi et al., 2019a). Hence, emissions from drained peatlands could be significant for Uganda's future transparent reporting and emissions reduction activities, especially if peatlands restoration activities are to be included in their pending second NDC. The same situation is likely for other Nile Basin countries with significant drained peatland areas, e.g. Rwanda, Burundi (See figure 4).

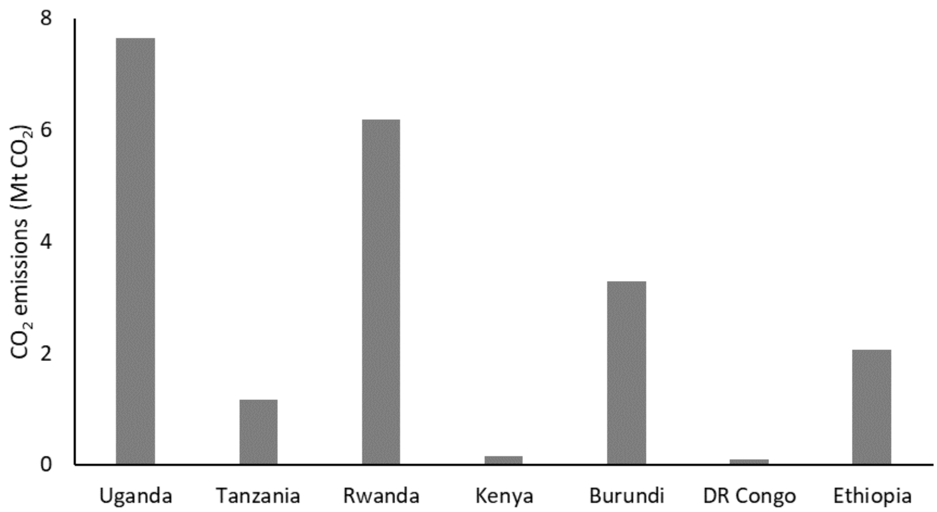


Figure 4. Average annual CO_2 emissions from drained peatlands within various Nile Basin countries in a business-as-usual scenario for the period 2015-2050. Note that national emissions from drained peatlands outside the Nile Basin are not included, e.g. DRC, and that information for S. Sudan, Sudan and Egypt is currently unavailable (Source: Elshehawi et al., 2019a).

Current estimates of Uganda's peatland is about 6,878 km^2 of peatlands (~3.7 % of the total national area) (Figure 1). Peatlands in Uganda are host to the Nile Basin's second-largest peat carbon pool (1.3 – 3.1 GtC). These peat landscapes are predominantly formed by freshwater swamps dominated by exuberant papyrus (*Cyperus papyrus* L.) stands and other sedges (Elshehawi et al., 2019a).

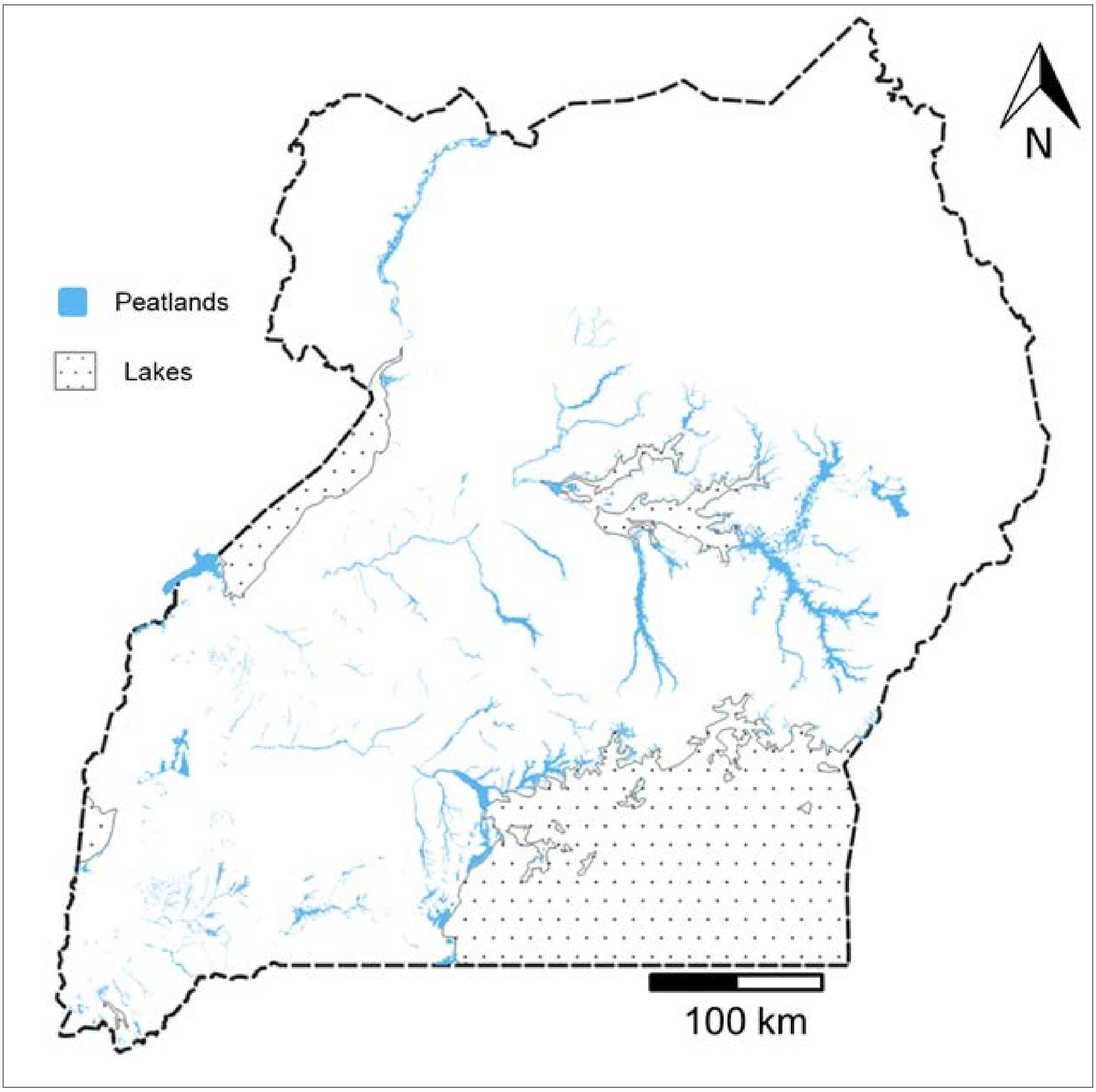


Figure 1. Peatlands distribution in Uganda (Source: Elshehawi et al., 2019a).

Papyrus is often present in the form of a floating mat that can be up to 1 m thick (Kayendeke et al., 2018; Elshehawi et al., 2019a). The floating mat thickness is often at its minimum at the fringes and reaches its maximum in the middle. The average mat thickness changes through the wet and dry seasonal cycles (Figure 2) (Kayendeke et al., 2018). The floating mat is often underlain by a water column that varies in depth through the dry and wet season. Below the water column, a peat layer can be present at the bottom of a varying thickness from a few centimetres to several meters (Elshehawi et al., 2019a).

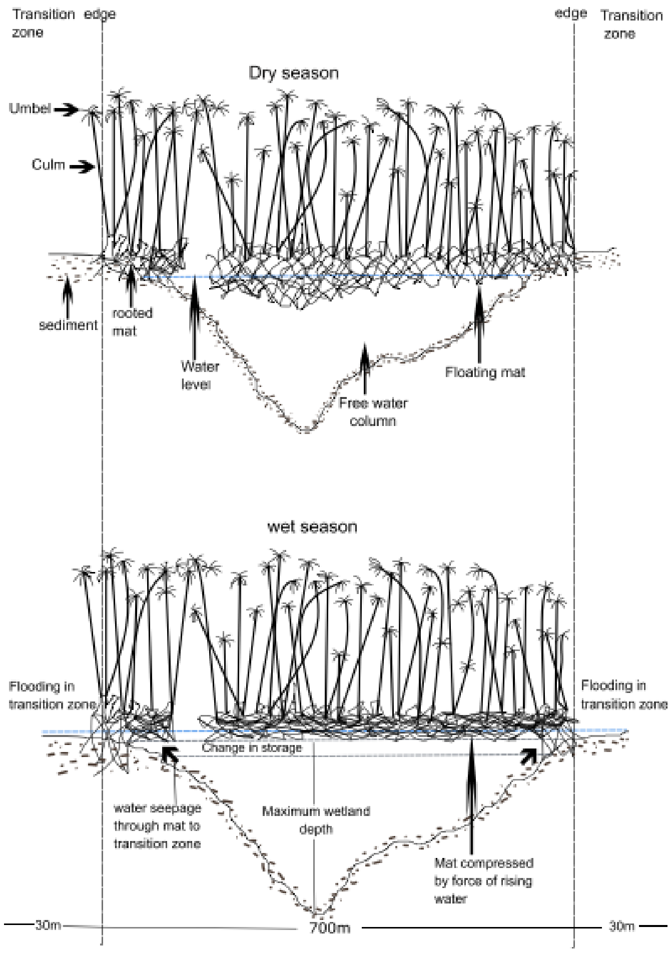


Figure 2. Papyrus floating mat dynamics in the dry and wet seasons (Source: Kayendeke et al., 2018).

The report builds on the results of the study on CO_2 emissions avoidance potential from the Nile Basin peatlands, which was part of the baseline studies on the Nile wetlands and their ecosystem services, particularly in relation to climate change mitigation, and their integration in the river basin planning (cf. Elshehawi et al., 2019a and b). Following up on the results from NBI's research, the aim is to stimulate the inclusion of mitigation and adaptation activities to reduce greenhouse gas emissions (GHG) from drained peatlands in Uganda's climate policies, particularly its Nationally Determined Contributions (NDC) and stimulate similar efforts in other NBI countries. Therefore we focus in this report on two technical elements: a) improving the MRV status mainly through exploring to improve land cover classification, as per IPCC categories for the peatland areas and b) exploring climate smart potentials to use drained peatlands within rewetting schemes for communities' livelihoods options. Lastly, we present a policy recommendation informed by the project's team-members participation in several workshops to disseminate and discuss the project's technical outputs on peatlands inclusion in national policy plans within Uganda and other NBI countries.

MONITORING, REPORTING AND VERIFICATION

Accurate and reliable information on the land cover distribution is important for monitoring, reporting and verification (MRV) of GHG emissions from peatlands. The current emissions estimates are based on the mapping activity from 2013 and its update in 2019, on the basis of ground-truthing, which differentiated peatlands into three classes: undrained, slightly drained and heavily drained (Elshehawi et al., 2019a). The latter two classes were then attributed the IPCC emission factor for drained peatlands, i.e. Tier 1 (IPCC, 2014). Differentiated emission estimates on the basis of land cover is therefore the necessary next step to monitor, report and verify more accurate estimates for GHG emissions within Tier 1. It may also be used to identify the dominant land covers, which may be prioritized for direct and indirect greenhouse measurements to have Tier 2 emissions.

Methods

We checked the suitability of two recent land cover products for accurate reporting on land cover types on peatland areas: the Copernicus Global Land Cover (Copernicus) and Climate Change Initiative-European Space Agency African land cover (CCI-ESA) with spatial resolutions of 100 m and 20 m, respectively (Table 1). We analysed the products against our ground-truthing data and corings available from literature (Figure 5).

Table 1. Summary of the main characteristics of the global land cover products.

Dataset	Spatial resolution	Period of data acquisition	Sensor	Classification method	Classification scheme	Overall accuracy
CCI-ESA 2016	20m	2015-2016	PROBA-V	Supervised classification	FAO LCCS 10 classes	75%
Copernicus	100m	2015-2019	PROBA-V	Unsupervised and supervised classification	FAO LCCS 10 classes	74.3%

The European Space Agency (ESA developed the ESA-CCI S2 prototype (2016) map with a spatial resolution of up to 20m of African land cover) Sentinel-2A observations during December (2015-2016) were used. The phase II dataset has a spatial resolution of 20 m and is based on 7-day composites Sea and Land Surface Temperature Radiometer (SLSTR) and Time series of Sentinel-3 Ocean and Land Colour Instrument (OLCI) and from 2016 with 75% overall accuracy (ESA, 2017). The CCI-ESA 2016 dataset has a legend with 10 land cover classes that described through the Food and Agricultural Organization’s (FAO) Land Cover Classification System (LCCS). The method is a combination of supervised classification of 10 land cover categories, including: Forestland, shrubland, grassland, cropland, regularly flooded, lichen/mosses, bare areas, built-up areas, open water and snow/ice. The validation process for CCI-ESA 2016 is evaluated using the GlobCover 2009 validation dataset, for example in the GlobCover validation exercise included two different processes: collecting reference data sources and assessing the map's accuracy. The classification in the dataset was validated by the experts not involved in the classification process (ESA, 2017).

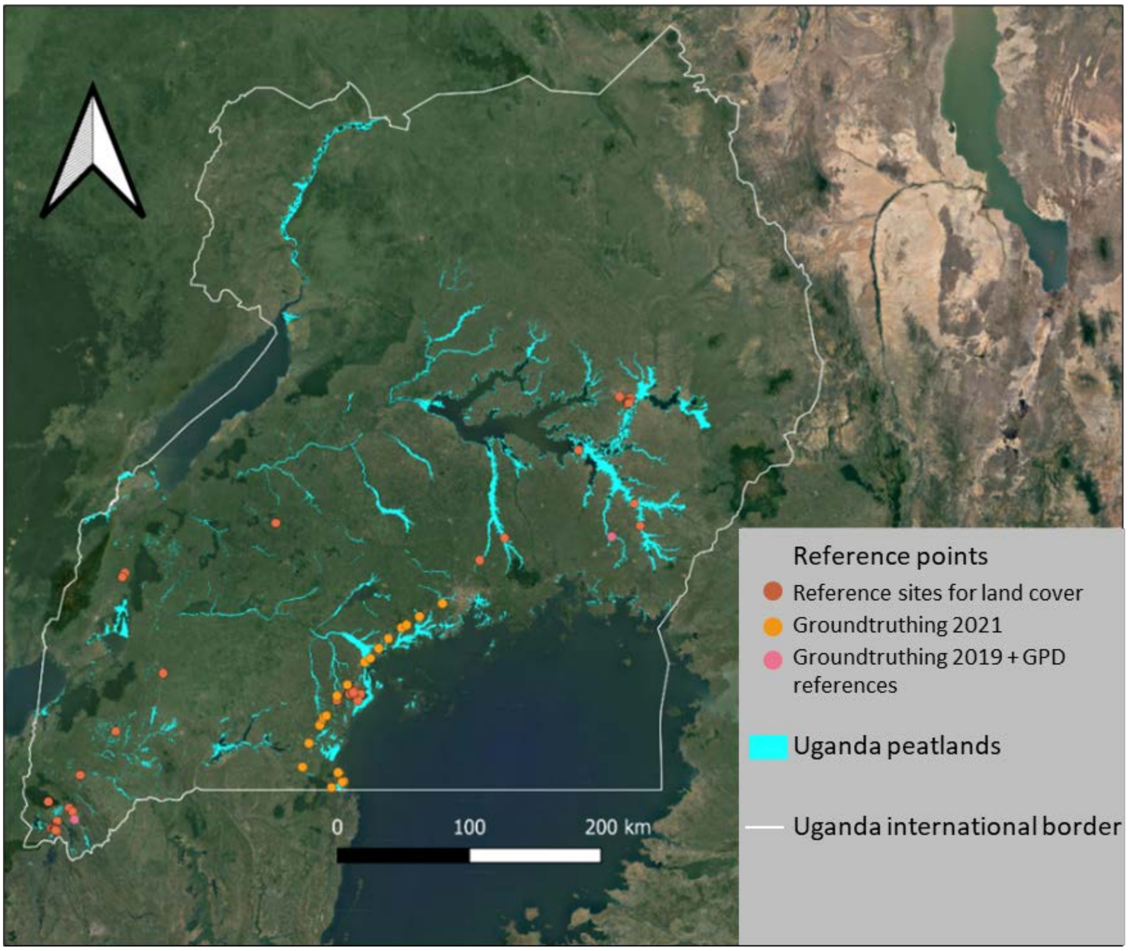


Figure 5. a- ground-truthing sites visited in 2019 (dark orange) and 2021 (light orange) and global peatland database reference points, b- land use data from Kayendeke et al. (2018) and Langan et al. (2019) (pink).

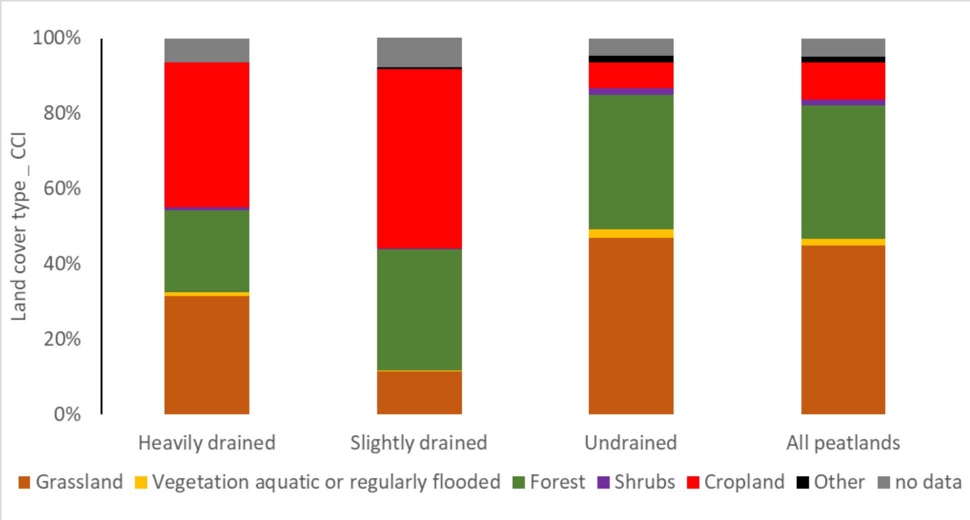
The Copernicus product has four consecutive global land cover maps for five years i.e., 2015, 2016, 2017, 2018, and 2019, with a spatial resolution of 100 m. Google maps and Bing imagery at a 10 m spatial resolution were used for a manual classification to collect the training data. The classification combines supervised and unsupervised classification using Random Forest techniques. It is a product of Copernicus Global Land Services (CGLS) to provide global land use coverage based on 100m spatial resolution. With a 5-daily multispectral VEGETATION instrument on board of PROBA satellite (PROBA-V) 100m multi-spectral image data as a primary Earth Observation data (EO) and PROBA-V 300m daily multi-spectral image data as a secondary EO data were adopted to obtain the four different maps. In this study, we used the 2016 global land cover map, with a legend based on the Land Cover Classification System with 10 classes i.e., Forestland, shrubland, herbaceous vegetation, herbaceous wetland, moss/lichen, Bare/Sparse vegetation, cropland, built-up, snow/ice and permanent water bodies. The Copernicus map has an overall accuracy of 74.3%, and the Copernicus product better characterizes natural vegetation categories from visual comparison with other global land cover products (Buchhorn et al., 2020).

Results

The analysis of the existing Copernicus and CCI-Africa land cover of peatlands showed that the peatlands mapped by the Global Peatlands Database (GPD) in 2019 (Elshehawi et al., 2019a) are similarly made up of Aquatic vegetation/Grassland, forests, herbaceous vegetation, croplands, shrubs and other land types (mainly urban land, open water and bare areas), respectively from most to least (Figure 6). The peatland proportion areas of the Copernicus product and the CCI_ESA 2016 product have different land cover types. They are also inconsistent with the land cover types of the reference dataset.

The composition changes when the land cover is classified per the drainage status of the peatlands (undrained, slightly drained or heavily drained). Croplands, herbaceous vegetation and shrublands, respectively from most to least, increased and showed a correlation with the drainage status of the peatlands. The high proportion of the forest cover within the peatland areas is likely to be a classification mismatch in most cases.

The analysed products are limited in differentiating drained peatlands from undrained ones when papyrus is the dominant vegetation in both cases, especially for areas indirectly affected. For instance drainage for infrastructure like roads, which cannot not reflected in the land cover products by remote sensing due to their limited spatial cover, even in the own classification practice. Other indirect impactful may be activities that affect the peatlands water budget like hill-slope afforestation and upstream agriculture with high nutrient release, which leads to higher GHG emissions. Overall, ground-truthing and site specific knowledge are irreplaceable in such cases to monitor peatland status properly.



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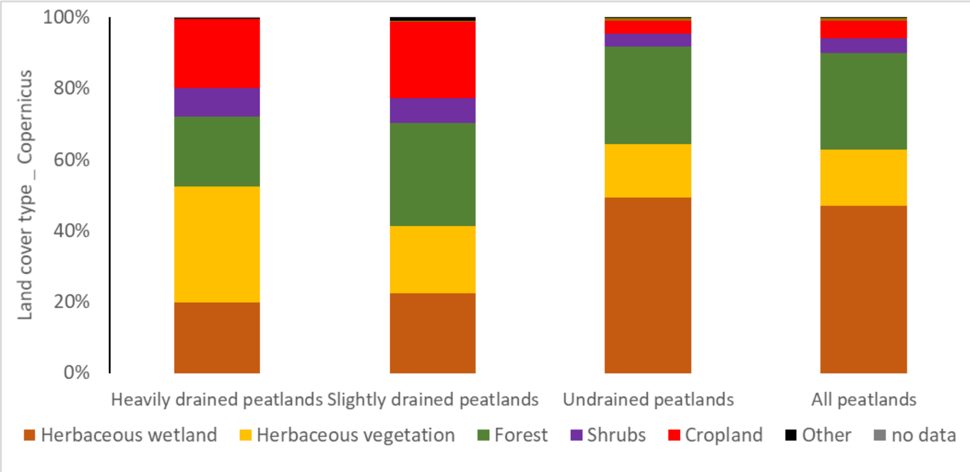

b)

Figure 6. Percentages of the land cover types overlaying the peatland areas in Uganda, a) Copernicus land cover product 2016 and b) CCI Africa land cover product 2016.

Overall and despite the classification mismatches, the land cover data indicate that the greenhouse gas estimates for the drained peatlands made in 2019 are very likely to be robust (See figure 4) and rather conservative, i.e. emissions estimated are likely to be lower than the actual situation. Both products show that the cropland cover in 2016 is about 10-12 % of the total peatland areas. They also show a higher proportion of herbaceous vegetation and shrubs in peatlands classified as slightly or heavily drained, which indicates that these classes are associated with peatland drainage. These classes make up about another 3-5 % of the total peatland areas.

For forest classes, it is harder to distinguish whether they indicate peatland drainage or they result from misclassification. Therefore, we are unable to draw conclusions from their classification. Own supervised classification using Sentinel-II data indicated that the majority of the peatland area classified as forest were a mismatch, and that papyrus vegetation is often misclassified as forest cover

(Ssemambo, 2022). In the field, it was noted that drained peatlands tend to be encroached by trees, shrubs and other herbaceous vegetation, which is classified as forests in the land cover products, however further systematic analysis and ground-truthing needs to be done for confirmation. The forest classes make up 25-35 % of the peatlands area in the land cover products, which highlights the importance to fix this issue to the future land cover mapping.

Recommendations

The existing land cover products from Copernicus and CCI-ESA 2016 are not suitable to base greenhouse gas estimates solely on land cover. Nevertheless, they provide necessary inputs for Tier 1 and possible future Tier 2 MRV systems as a cost and time efficient approach to calculate rough annual greenhouse gas emissions from drained peatlands. They may serve as a base map for investigation of the annual changes, where only Copernicus provides annual land cover products. Hence, Uganda will need to develop its own land cover for the peatland areas. This can be done by running own remote sensing classifications on annual basis, which may be expensive and technically challenging. Also, it will not compensate for the need for extensive ground-truthing campaigns.

Another option may be creating land cover maps through a hybrid remote sensing (using the existing products) and ground-truthing inventories at the district level every 3-5 years. For Tier 2 emissions estimates, specific greenhouse gas measurements, i.e. gas chambers or eddy covariance, need to be carried out for the different land cover types, which is so far nearly non-existent and would require expertise, capacity and resources to develop. Alternative methods to calculate greenhouse gases like water level monitoring and subsidence are cheaper and require less technical expertise. They may be suitable to develop in the short term, while emission specific for the different land covers are developed.

The analysed land cover products can be used in combination with water level monitoring and/or subsidence to prioritise areas that are hotspot for land use and/or drainage. Similarly, these land cover maps can be used to prioritise areas for rewetting and paludiculture soon. In conclusion, technical expertise through capacity building on the aspects of peatland mapping (including remote and on-site expertise), land cover and greenhouse emissions monitoring, reporting and verification are urgently needed to facilitate the inclusion of, and implementation, greenhouse emissions mitigation from drained peatlands in Uganda.

Other Nile Basin countries with high emissions from drained peatlands may also benefit from the research advances on greenhouse emissions monitoring in Uganda. Uganda hosts various types of peatlands that are representative of all of the peatland types present within the Nile Basin, i.e.

landscape types and climate zones. Despite that, similar exercises should be performed in the countries with hotspots of greenhouse gases emissions, e.g. Rwanda, Burundi, to ensure (verify) that emission factors developed in Uganda may be adopted by other countries in the region.

PALUDICULTURE: VALUE CHAINS OF PAPYRUS UNDER REWETTING SCHEMES

Paludiculture is a concept coined by peatland experts in Greifswald University, which defined this practice as the "agricultural or silvicultural use of wet and rewetted peatlands" (Wichtmann et al., 2016). This climate-smart alternative cardinally differs from the BAU drainage-based peatland use, which results in vast emissions of nutrients and GHGs, and ultimately undermining the peat body's stability (i.e. subsidence, peat fires) (Wichtmann et al., 2016). Although this productive use of peatlands implies a paradigm shift in conventional agricultural techniques, it allows the rehabilitation of essential ecosystem services and natural capital of wet peatlands, e.g. carbon sequestration and storage, nutrient retention, hydrological balance, etc. Furthermore, paludiculture fosters communities' livelihoods like traditional peatland cultivation (e.g. reed mowing) and stimulates promising uses like biomass for energy purposes (Wichtmann et al., 2010; Joosten et al., 2016).

Nonetheless, the implementation of paludiculture schemes should come as a rewetting alternative for disturbed peatlands. This should take place preferably after proper rewetting activities have recover the three main peatland's components (i.e. water, peat, plants). Paludiculture should be applied as an option where peatlands constitute an indispensable part of the productive land (i.e. agri- and horticulture) (Schumann and Joosten, 2008).

In tropical peatlands, paludiculture has been more extensively implemented in Indonesia, where intensive agriculture (e.g. industrial plantations, smallholder farming) has resulted in the drainage of > 60 % of peat swamp forests and amplified peat fire events. Experiences have focused on cultivating high-quality non-timber flora (e.g. Jelutong, Tengkawang nut trees, Rattan palm trees). This in turn have helped to diversify local economy and transform livelihoods. Nonetheless, current yields of the non-timber species have collapsed due to overexploitation, raising the alarm towards sustainable harvesting practices (Giesen and Boissevain, 2013; Wichtmann et al., 2016).

Considering Uganda's land-use change dynamics and further environmental problems associated with peatland drainage and traditional uses of papyrus, paludiculture stands as an inclusive solution to avoid further reclamation of these highly productive, culturally relevant, and carbon-rich ecosystems while contributing to the country's climate agenda (Elshehawi et al., 2019b). Likewise, a sound design and implementation of papyrus paludiculture scheme could provide diverse business opportunities for wet and rewetted peatlands while advancing towards emissions avoidance and climate-conscious livelihoods (Tapio-Biström et al., 2012; Elshehawi et al., 2019b).

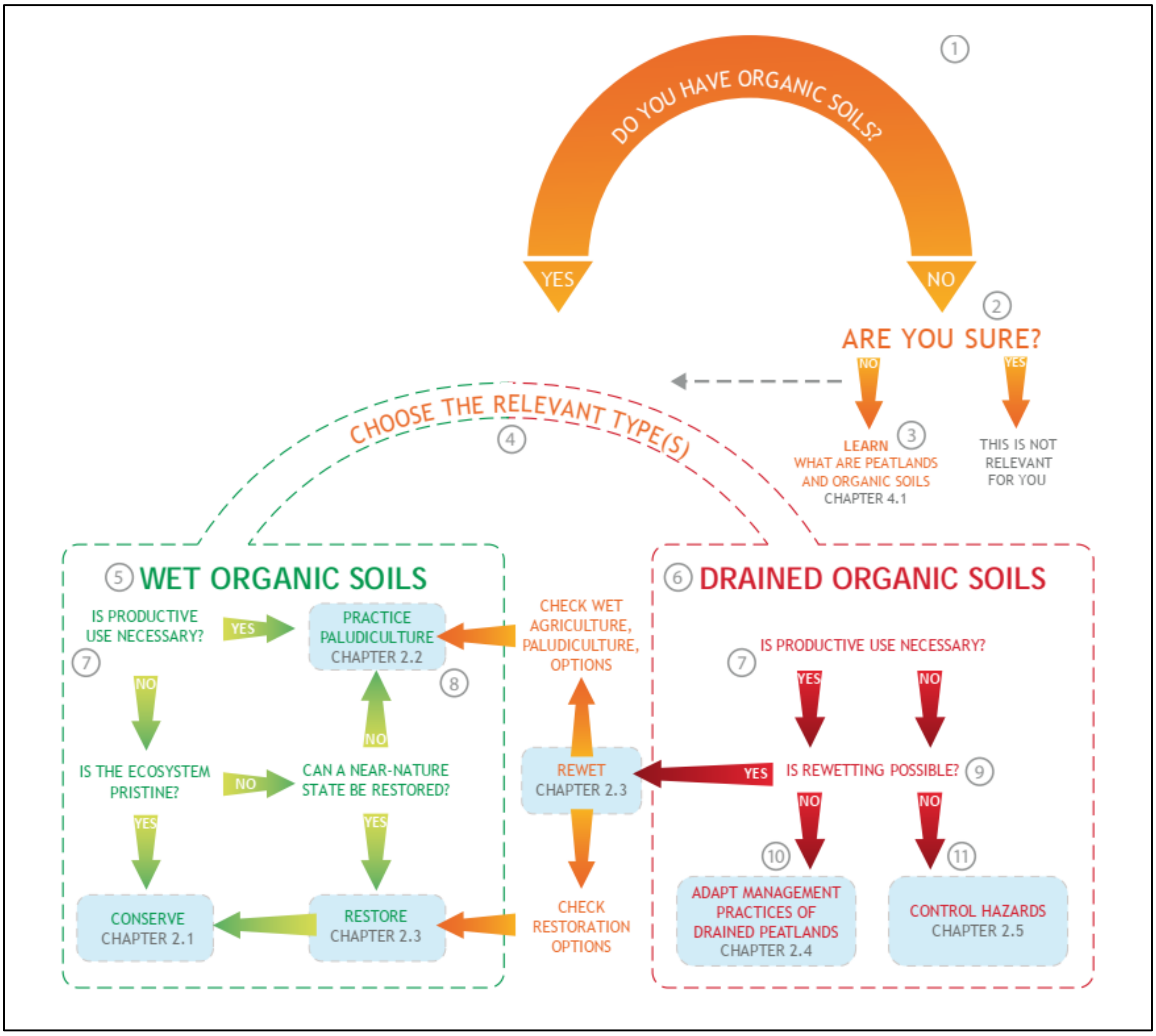

Figure 7: Decision support tree for management of peatlands and organic soils (from Tapio-Biström et al., 2012)

Methods

This study is centred on understanding the full chain of activities, values, and actors involved in manufacturing traditional and potentially innovative products yielded from papyrus peatlands to render innovative paludiculture schemes in Uganda. A value chain analysis approach was outlined accounting the guidelines and methodological viewpoints from Hellin and Meijer (2006) and FAO & UNDP (2020). This approach targets to gather a comprehensive dataset for mapping out traditional and potentially innovative papyrus paludiculture value chains from a climate resilience standpoint.

Nonetheless, due to Pandemic restrictions, the data collection could only provide the status quo of the value chains activities and actors.

Conceptually, a value chain analysis seeks to identify actors' interactions at each stage of the chain, define the chain's governance, pinpoint added value activities, and characterize the flow of goods and services (FAO & UNDP, 2020). Initially, a value chain analysis starts by mapping out a simplified value chain (Figure 8) through qualitative or quantitative tools, ultimately resulting in the characterization of the interactions and value flows among actors and value chain stages. The latter helps to outline a full market map with a broader perspective composed by a value chain render with the actor's interactions, value flows, enabling environment and the business & extension services (Hellin & Meijer, 2006).

Figure 8. Simplified value chain diagram. (Modified from Hellin & Meijer, 2006).

The potential availability of papyrus biomass (tons dry weight, tDW) was calculated using the peatland area from our work in 2019 including geographical distribution and drainage state of the peatlands in Uganda (Elshehawi et al., 2019a). Furthermore, an average Papyrus biomass productivity value was calculated from reported yield numbers on published studies carried out in the Nile Basin region (Jones and Muthuri, 1985; Muthuri et al., 1989; Muthuri and Jones, 1997; Boar, 2006; Mnaya et al., 2007; Osumba et al., 2010; Terer et al., 2012b; Saunders et al., 2014; Jones et al., 2018).

A semi-structured interview methodology was designed to analyse the actors' views of the identified papyrus potential value chains (See Appendix). Initially, the interviews were categorized as cases containing the interviewees' answers transcription exclusively[2]. Furthermore, a focus group meeting was held during the Uganda Peatland Week in January 2022.

To further organize the data and the respondents' perspectives, the cases were open coded, aiming to identify key concepts and elements within the raw data concerning papyrus peatlands, papyrus use, products' value chains, and market players. Furthermore, related codes were grouped into categories (or axis) which were further clustered into core categories, ultimately comprising the traditional or potential innovative product's value chains. Lastly, the data acquired from the focus group activity

[2] To analyse these interviews, each one was recorded and then transcribed with Otter.ai, a speech-to-text transcription software ("Otter Voice Meeting Notes - Otter.ai," 2021). The transcripts were then processed and analysed with the software for qualitative data NVivo 1.5 (Bryman, 2012; Qualitative Data Analysis Software|NVivo, 2021).

was systemized in Excel and statistically analysed in Rstudio V2021.09.1+372. For answers 1, 2 and 6, word clouds were generated with the Nvivo word frequency option.

Results

Potential products and value chains

Papyrus biomass has a wide range of uses according to the quality, state and section of the plant harvested (e.g. rhizome, culm or umbel). For Uganda, which was used as an incubator for other peatland-rich countries in the Nile Basin, papyrus has an estimated total annual yield of 504,993 tDW. Following a snowball sampling, local actors, stakeholders and entrepreneurs were identified and contacted via local wetland officers and environmental authorities to establish an heterogenous panel of 14 interviewees. In the performed interviews, local stakeholders gave an overall outlook on peatlands with papyrus vegetation cover, traditional uses of the biomass and innovative practices. They indicated that there is a heritage link and corresponding appreciation towards traditional uses although the daily utilization of traditional commodities has been diminished over time. Novel goods made from papyrus are still not common on the local market.

Local stakeholders' perspectives remains willing to open market alternatives for the use of innovative papyrus products and paludiculture as a sustainable livelihood alternative. Similarly, entrepreneurs' position shows to be in favour to promote the implementation and further optimization of novel value chains and synergetic papyrus paludiculture schemes. Such innovative schemes may facilitate papyrus harvesting, processing, trading, retailing, and commodities manufacturing and vending. Acknowledging respondents' contributions, four categories of papyrus products were identified and classified according to the purpose of the biomass use as detailed in Table 2.

According to the interviews and the identified products (Table 2), papyrus products related to livestock and agriculture (i.e. fodder and mulching), and raw material for paper, crafts (e.g. baskets, mats, brooms), construction and fishing gears manufacturing, were defined as traditional. Meanwhile, interviewed stakeholders responded positively to high-quality construction materials, packaging, carbonized or non-carbonized pellets or briquettes (for energy) and sanitary (i.e. MakaPads) Papyrus commodities as possibly promising alternatives to use Papyrus raw material and complement local livelihoods in a sustainable manner. From our research, we were only able to identify energy (i.e. carbonized and non-carbonized pellets or briquettes) and sanitary related goods as locally produced commodities in Uganda.

Table 2. Traditional and innovative papyrus products in four categories mentioned in interviews

Product category	Product
Livestock & Agriculture	Fodder, Mulching
Raw material	Construction (e.g. roof thatching, fencing, walls), fish traps, paper, crafts (e.g. baskets, mats, brooms), packaging
Energy	Briquettes (carbonized / non-carbonized), pellets
Others	Food, biochar, sanitary pads

The elaboration of innovative construction materials (e.g. building panels), packaging and other high-quality products requires one or more pivotal processing stage after harvesting, drying, trading and retailing of the papyrus raw material. The critical processing phase requires specialized machinery and personnel qualified to handle the equipment adequately to manufacture papyrus building supplies and generate packaging (Figure 9).

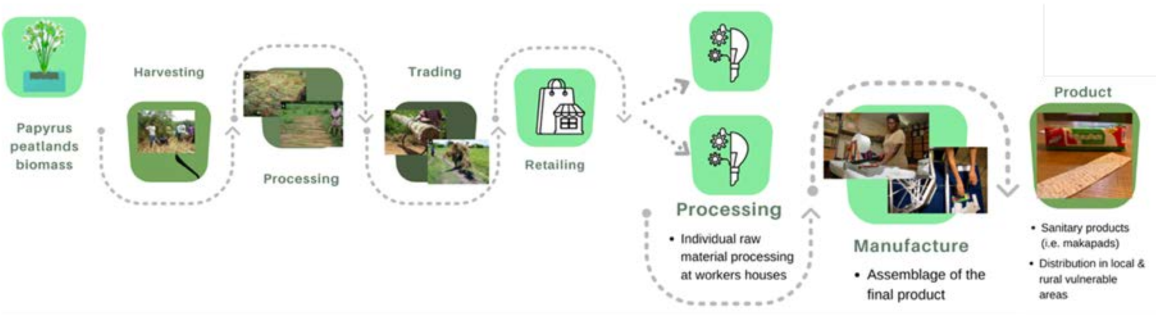

Figure 9. Exemplary papyrus value chains for sanitary products.

Traditional products

Traditional papyrus commodities identified by this study (Table 2), match with other findings in Lake Bunyonyi and Nakivubo (Uganda), as well as in bordering shores of Lake Victoria in Kenya and Tanzania. Widespread use of papyrus biomass for crafts making (e.g. mats, baskets, trays), roof and fence construction, rope elaboration, etc. has been observed by multiple studies, which underlines the pivotal role papyrus commodities have in local microeconomics and livelihoods (Emerton et al., 1998; Maclean et al., 2003a; Ojoyi, 2006; Morrison et al., 2012; Terer et al., 2012b; Gaudet, 2015; Donaldson et al., 2016; Langan et al., 2018). This was reinforced in the statements made by multiple local actors during the interviews concerning the economic value of papyrus as a wetland crop and the potential yielded commodities: “Papyrus is a crop that grows in our wetlands and predominantly what we do is, use it for many purposes… It is a crop with economic value”, “We use this papyrus for making mats, we also use papyrus for thatching our houses. We use it for mulching. Making baskets”, “…so generally it is an income generating crop or plant benefiting the people around the shores of Lake Victoria”.

The focus groups responses indicated that baskets, mats and crafts (traditional goods) are highly commercialized papyrus market commodities in districts like Masaka in central Uganda (Figure 10). In other East African countries (i.e. Kenya, Rwanda, Burundi, Tanzania, Ethiopia), papyrus is commonly used for medicinal purposes, as a food source (i.e. livestock grazing), roofing and fence construction, craft making (e.g. baskets, trays, sleeping mats, ropes), which provides a steady source of income for communities living in peatlands proximities during the dry season (Donaldson et al., 2016; Kipkemboi and van Dam, 2018; Lusasi, 2016; Maclean et al., 2003b; Morrison et al., 2012; Terer et al., 2012a; van Dam et al., 2011). This trend indicates that the use of papyrus biomass is tightly linked to the traditions, culture and livelihoods of rural communities living next to peatland areas (Emerton et al., 1998; Maclean et al., 2003a; Terer et al., 2012a). Nevertheless, traditional products are sold in the market for a relative low price. Therefore, their potential for up scaled support for livelihoods aside from covering very basic needs is currently low, unless other factors like innovations in processing to higher value products come into play (e.g. technology advances).

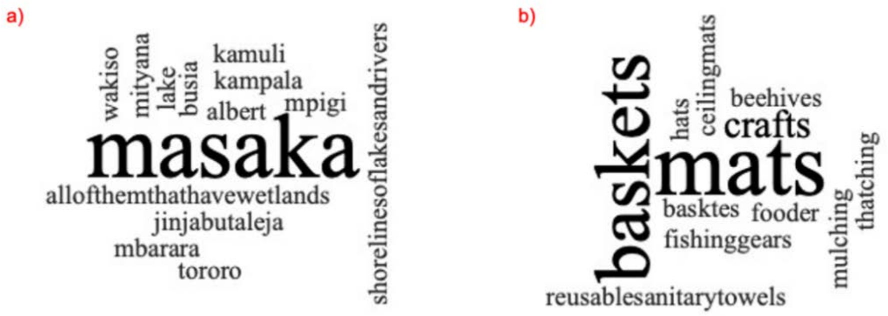

Figure 10. Word clouds from (a) Q1: Which Ugandan districts are(is) known for their traditional use of papyrus? (N=16); and (b) Q2: Which of the traditional papyrus products showed are mostly used or available on the market? (N=22). Bigger words represent most frequent answers.

Innovative products

The potentially innovative uses cited by entrepreneurs constitute a pivotal opportunity to unlock pioneering sustainable benefits of peatlands biomass. They may act as a critical supply to fulfil the increasing raw material, energy and sanitary market needs, while supporting climate-smart livelihoods in the NEL region (Saunders and Jones, 2017). Studies also suggest a promising potential in the use of raw biomass as a competitive high-value biofuels, e.g. sugar cane ethanol, peatland biomass biogas plants, biochar, which are already in use in other regions in the tropics and the temperate zones (Faaij, 2006; Avellan et al., 2017; Rodriguez-Dominguez et al., 2021).

For instance, a briquette making entrepreneur mentioned in the interview, “Papyrus that's for sure. It would come in handy as raw material to produce non-carbonized briquettes, because you can easily access the papyrus around Kampala.” Several studies have already stressed the potential that papyrus has as a source of biomass for energy in sub-Saharan Africa. Papyrus can support sustainable peatland use on rewetted, formerly degraded sites and replace fuelwood consumption while satisfying local domestic energy requirements by more than 80%, which means that firewood should be used to supply less than 20 % of households energy demand (Morrison et al., 2014; Jones et al., 2018).

The implementation of optimization techniques developed by a leading research institution (i.e. “Fuel from the Fields” by MIT) can also help to improve the commodities’ characteristics. It can increase its calorific value by 33 % (compared to wood charcoal) and reduce papyrus’ volatility by 50 %. In turn, it would contribute to reducing further pulmonary health problems (Morrison et al., 2014).

Papyrus photosynthetic pathway (C4) and high productivity (11.63 – 86.91 t DW ha-1 yr-1) facilitates a steady supply of raw material for the manufacturing of briquettes and other similar papyrus commodities (Jones et al., 2018), compared to similar emergent sedges (Joosten et al. 2016). Comparing papyrus versus European paludi-crops (i.e. *Phragmites australis, Carex spp., Phalaris arundinacea*), papyrus stands as a competitive paludi-crop acknowledging its high productivity and total moisture (carbonized biomass) compared to reed, sedges and reed canary grass.

Although incomparable, carbonized papyrus biomass has a similar calorific value compared to sedges and reed canary grass (Table 3) (Morrison et al., 2014; Dahms et al., 2017). Nevertheless, it is critical to foster comparative researches between carbonized and non-carbonized papyrus biomass, and promote experiences, traditional knowledge, and learned lessons exchange with experienced stakeholders to unlock a competitive papyrus biofuel market in Uganda and the NEL region.

The development of a clean energy market based on papyrus biomass seems to go in line with the local market’s demand and projections. Morrison et al. (2014) similarly underlines papyrus biomass briquettes as a promising natural source of energy in East Africa that can help to supply domestic fuel requirements by more than 80 % while reducing forests’ logging pressure for wood charcoal production. Consequently, implementing an organized papyrus paludiculture scheme in Uganda stands as a reasonable opportunity to foster the sustainable use of peatlands, while adding to the national climate targets and providing a sustainable livelihood to the actors engaged in the papyrus commodities' value chains.

The fabrication of sanitary pads from papyrus falls into another value chain category, which is promising in the Ugandan context and could be of interest for other NEL countries. The processed biomass is fundamentally centred to impact local health security and livelihoods positively. The entrepreneur leading the assembly of papyrus sanitary products (i.e. Makapads) indicated that their market "*is focused on woman and girls who live in poverty or are in the rural areas, since studies have shown that 80 % of them do not have access or cannot afford sanitary pads, and tend to drop off school*". Since 2004, Makapads have been available exclusively in the Ugandan market, essentially targeting their production to aid and cooperate with vulnerable local women to foster their sanitary safety and improve their livelihoods. The entrepreneur envisions Makapads branching out to neighbouring countries and providing competitive sanitary safety to rural women. Therefore, this scenario would require a steady supply of > 100 Kg/month of milled and dried papyrus biomass per factory, which may be provided from small scale restoration projects, e.g. rewetting and use of 1-2 hectares.

*Table 3. Combustion properties and productivity comparison between Papyrus sedge and European paludi-crops (Dahms et al., 2017; Morrison et al., 2014). ** Carbonized biomass (cuboid) * Non-carbonized biomass (pellets)*

Properties	**Papyrus (*C. papyrus*)****	**Reed (*P. australis*)***	**Sedges (*Carex* spp.)***	**Reed canary grass (*P. arundinacea*)***
Productivity (t DW ha^{-1} yr^{-1})	11.63 – 86.91	12	6.5	10
Calorific value (MJ kg^{-1})	20.04 - 20.46	672 - 704	18.3 - 18.9	18.9 - 19.0
Total moisture (wt%)	7.35 – 9.07	9 - 10	11 - 13	12

The traditional and potentially innovative papyrus goods found by this research are comparable to the peatland biomass uses shown by other studies in temperate regions (Wichmann, 2015; Joosten et al., 2016; Becker et al., 2020). For example, focal peatland species like cattail (Typha spp.) and reed (Phragmites australis), have been used as raw materials, fodder, food sources, energy and agricultural conditioners to provide construction, furniture and agricultural sustainable as sustainable growing mediums alternatives while assisting the rewetting of large peatland areas in northern Europe, and contributing to national and international climate agendas (Wichtmann et al., 2016; Tanneberger et al., 2020; de Jong et al., 2021). This has, in turn, aided the expansion of the local and international market for the commercialization of paludiculture commodities and fostered the optimization of the production value chains (e.g. specialized harvesting machinery) (Joosten et al., 2016).

Similarly in the tropics, Indonesia has further developed paludiculture initiatives targeting food crops (e.g. sago, pineapple, banana, dragon fruit, mangosteen, etc.), timber, and other non-timber relevant species, to combat peat fires, soil subsidence, and CO2 emissions and stocks, while providing alternative sustainable livelihoods to local farmers (Giesen and Boissevain, 2013; van der Meer et al., 2021). Considering that papyrus paludiculture and high-quality products bio-market, it becomes necessary to put in perspective national agricultural policies, land-use and wetland protection frameworks, investments costs, environmental hazards and demographics to provide a common and inclusive framework for papyrus paludiculture implementation (Budiman et al., 2020; Wichmann et al., 2020).

Entrepreneurs leading the potential innovative uses of papyrus in Uganda (i.e. sanitary products and energy-related commodities), declared that “the integration of processes with the company that's making sanitary pads, is a good combination to kind of collaborate with them”, and cited that “our vision is to open up different factories in different sections of different types of Uganda, to then make sure that these pads are affordable and accessible for everyone”.

This research proposes such a paludiculture scheme that integrates sanitary products and energy-related goods value chains to optimise both value chains through the utilization of the by-products generated on the sanitary commodities production as raw material for the fabrication of carbonized or non-carbonized papyrus briquettes or pellets. To optimize the proposed paludiculture scheme further, firstly is important to establish the required papyrus feedstock for both value chains. This research, calculated 4.7 M tDW per year as the potential papyrus yield available assuming that all drained peatlands are rewetted and used for paludiculture. Nonetheless, this harvest calculation requires further field validation accounting peatlands’ current drainage state, and crosschecking with papyrus’s local productivity values.

Recommendations

The implementation of paludiculture schemes requires further **awareness-raising** and **investment efforts** with a cross-sectional tactic aiming towards environmental literacy programs and the generation of environmental advocates in all sectors. It is necessary to put in perspective **national agricultural policies, land-use and wetland protection frameworks**, investments costs, environmental hazards and demographics to provide a common and inclusive framework for papyrus paludiculture implementation. Additionally, is fundamental to integrate governmental (e.g. MoWE), non-governmental institutions (e.g. NGOs, Carbon Fund Uganda), technology providers, academia, and business catalysts to gradually foster and upscale an environmentally sound papyrus bio-economy. The integration of the latter actors will provide a **full value chain map** combining the enabling environment, business and extension services, and value feedbacks among stakeholders, will help to put in place a more comprehensive and inclusive paludiculture scheme transferable to neighbouring NEL region countries and the wider tropical peatland community.

Furthermore, it is imperative to acknowledge that paludiculture is an **emerging, science-driven and collaborative world phenomenon** that fosters comprehensive bottom-up plans, while integrating the somewhat conflicting economic, social, political and environmental sectors to strive for a common goal, the productive and climate-smart use of peatlands (Ziegler, 2020; Ziegler et al., 2021). Outcomes of a recent international survey on paludiculture underline the evolving nature of this novel agricultural approach, the high interest in the **development of climate-inclusive commodities** (e.g. carbon-neutral, or even negative high quality construction materials and fuels), and its possible inclusion in national and global environmental and economic agendas given its link to circular economy (Ziegler et al., 2021). Applying and scaling paludiculture in Uganda and the NEL region will shape the way **to restore and reinforce the traditional know-how, while creating a climate-inclusive productive niche in a peatland conscious society**.

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2022 to complete the master programme of Landscape Ecology and Nature Conservation at the University of Greifswald, Germany. Interested researchers should refer to the thesis for full review.

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APPENDIX: ACTORS ANALYSIS AND INTERVIEWING METHODOLOGY

Step 1: Local actors and entrepreneurs' panel

Following a snowball sampling or chain referral strategy (Bryman, 2012; Newing, 2010), local wetland officers and environmental authorities were initially emailed to establish a heterogeneous panel of local actors, stakeholders and entrepreneurs with backgrounds in the fields of wetland conservation, papyrus management and use, and bioproducts manufacturing employing natural fibres or papyrus biomass. Next, a database of 28 local or key informants (bridge stakeholders) was gathered and then categorized by institutional affiliation and type of organization (i.e. academia, NGO, Env. Authorities, local actors, etc.). Lastly, the bridge stakeholders proposed 14 key entrepreneurs directly working with papyrus biomass, relevant local actors and/or papyrus wetland enthusiasts to book remote bilateral semi-structured interviews (Table 1).

Table 1. Shortlist of interviewees categorized by type, role and region of experience

Type	Role	Region of experience
Local actor	Local community coordinator, wetland conservation activities	Busia district (East Uganda)
	Wetland conservation activities, local community coordination	Busia district (East Uganda) – Sio Siteko wetland
	Wetland conservation activities, National farmer's federation youth projects facilitator	Masaka district (Central Uganda)
	Wetland conservation activities, environmental activist	Tororo (East Uganda)
	Wetland conservation activities	Lake Bunyonyi (Western Uganda)
	Wetland conservation activities, environmental activist	Western Uganda
	Wetland conservation activities, environmental activist	Kyotera district (Central Uganda)
	Wetland conservation activities, environmental activist	Kampala (Central Uganda)
	Wetland conservation activities, environmental activist	Rakai district (Central Uganda)
	Wetland conservation activities, environmental activist	Mabamba wetlands (Central Uganda)
Entrepreneur	Local community coordinator, wetland conservation activities, papyrus biomass use for crafts and traditional products	Masaka district (Central Uganda)
	Local community coordinator, wetland conservation activities, papyrus biomass use for crafts and traditional products	Mabamba wetlands (Central Uganda)
	Papyrus biomass transformation for sanitary uses, social activities, woman empowerment	Kampala (Central Uganda)
	Agricultural discard biomass transformation to carbonized briquettes	Kampala (Central Uganda)

Step 2: Semi-structured interviews

Following the local actors' and entrepreneurs' panel establishment, an interview guide was designed considering Bryman (2012), Newing (2010) and Young et al. (2018) guidelines. The bilateral interviews followed a structured set-up as specified in Appendix 2, starting with an introductory section, then a warm-up and focal questions part, and ending up with closing remarks. Between August and October 2021, 14 semi-structured interviews using Voice over Internet Protocol or VoIP technology (i.e. Zoom or Skype) standardly with a duration of 28 minutes each were conducted. Each respondent was asked open-ended questions to identify papyrus products, map out traditional and potentially innovative product's value chains, and pinpoint key market players.

Considering the ample flexibility semi-structured interviews provide for respondents to express their insights and knowledge of the concerning topic, and their comprehensive implementation in conservation science research (Bryman, 2012; Newing, 2010; Young et al., 2018). Therefore, the application of the latter qualitative method was considered a fitted alternative to fulfil this research's goals and surpass the contextual public health hurdles (i.e. COVID 19 pandemic) at the moment of the data collection.

Step 3: Online experts Forum (Focus group)

Focus groups are a widely implemented quantitative market research method to scan products' market potential and get first-hand feedback from actual users and potential customers (Parker and Tritter, 2006). Moreover, this technique has also been used in conservation biology as a cost-effective and promising way to implement participatory research (Nyumba et al., 2018). Fundamentally, focus groups consist of a group interview with a set of questions framed under a defined topic, which intends to encourage participants' reflection and fosters a retrospective analysis of the reasons behind the voiced views (Bryman, 2012; Newing, 2010).

A focus group consisted of local and international experts who were nominated by the bridge stakeholders and had experience in wetland conservation, paludiculture, and Papyrus peatlands (Table 2). The focus groups were outlined within an online experts' forum, which was organised under the project "DIAPOL-CE – Policy Dialogue on Low Emission Development: Political Dialogues for Climate Change and Peatland Management in the Nile Basin". The event was remotely held via Zoom on August 16th 2021, and focused on fostering multilateral dialogues between the stakeholders and local expert's panel to identify traditional and innovative papyrus value chains and products and delineate likely potential paludiculture strategies for Uganda. After a series of introductory and contextualizing talks, an interactive and live questions session (questions listed in Table 3) was conducted using "PollEverywhere", which is an online dynamic polling platform.

Table 2. Focus group attendees

№	Institution/Role	Stakeholder type
1	Trinity College Dublin	Academia
2	Austrian Dev. Agency	International environmental partners
3	Wetlands Management Department, Assistant Commissioner	National environmental authorities
4	Masaka Enviroment Officer	National environmental authorities
5	Wetland and Marine Section, Centre for Biodiversity Department, National Museums of Kenya	National environmental authorities
6	AYOWECA	NGO/Research
7	Uganda Carbon Bureau	NGO/Research
8	Local	NGO/Research
9	Local	NGO/Research
10	GIZ Uganda	International cooperation institution
11	GIZ	International cooperation institution
12	GIZ	International cooperation institution
13	Michael Succow foundation	Peatland research institution
14	Michael Succow foundation	Peatland research institution
15	Greifswald Mire Centre	Peatland research institution
16	Nile Basin Initiative wetlands' desk	International cooperation institution

Table 3. Focus group questions

№	Question	Answer output
Q1	Which Ugandan district(s) are(is) known for their traditional use of papyrus?	Word cloud
Q2	Which of the traditional papyrus products showed are mostly used or available on the market?	Word cloud
Q3	Which of the presented innovative types of use (construction materials, insulation, packaging, energy, etc.) is the most promising in your perspective?	Open answers (Text wall)
Q4	Which innovative product you see yourself using on a daily basis?	Multiple choice histogram
Q5	What needs to be done to bring innovative papyrus products to the market?	Upvote/Downvote answers
Q6	Which institutions (governmental and non-governmental) could be involved in a Papyrus paludiculture program?	Word cloud

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