Stockholm University

Bachelor Thesis

Degree Project in
Geology 15 hp

Can rewetting of peatland significantly slow down climate change?

A mitigation scenario based on carbon storage potentials from selected European sites

Claudia Windeck

Stockholm 2017

Department of Geological Sciences
Stockholm University
SE-106 91 Stockholm
Sweden

Abstract

Peatlands currently cover about 500 000 km^2 of European land, of which 219 000 km^2 (Joosten, 2009) have been drained for agriculture, forestry or peat mining. Reported values for total emissions of climate forcers, given in CO_2 eq, range from 30 to 60 t CO_2 eq ha^{-1} yr^{-1} (Wichtmann, 2016) for drainage based peatland utilisation. Strategies of adaption and mitigation for coping climate change include the importance of peatlands and the potential of restoring their natural function as carbon sinks.

The aims of this thesis were to investigate whether large-scale re-establishment of natural conditions in degraded European peatlands might promote the natural ability of peatlands to act as major carbon sinks in the context of climate change mitigation. Furthermore, based on emission factors, the costs of restoration measures as well as carbon and non-carbon benefits, the feasibility and profitability for different restoration scenarios in percentages of the currently degrading peatland area were evaluated.

The results show that cost of restoration measures is not inconsiderable, with an average cost of 4735€ per hectare. However, intact European peatlands have the ability to store 7.8 t CO_2 eq ha^{-1} yr^{-1} leading to a significantly reduced global warming potential of 1.8 t CO_2 eq ha^{-1} yr^{-1} compared to average emissions of 3.9 t CO_2 eq ha^{-1} yr^{-1} for drained peatlands. After considering the financial benefits from selling carbon credits on compliance and voluntary carbon markets as well as cost reductions by avoiding emissions, the conducted cost-benefit analysis clearly confirmed the profitability of large-scale peatland restoration in Europe.

Table of contents

1) Introduction

In the course of the current climate debate, strategies of mitigation and adaption for coping with climate change are urgently sought. In this context, peatlands come into the field of vision, as the definitions “peatland” and “climate” are strongly interrelated. The significant climate relevance of peatlands can be recognised by understanding peat formation processes leading to their function as enormous storage reservoirs for carbon dioxide. Carbon accumulation rates are expressed in LORCA (**L**ong-**T**erm-apparent-**R**ate-of-**C**arbon-**A**ccumulation) and have been reported to vary between 0.15 – 1.5 t C ha^{-1} yr^{-1} for Europe's boreal and temperate regions, strongly depending on vegetation, climate and peatland type (Joosten and Clarke, 2002; Höper, 2007; Tolonen and Turunen, 1996). Decomposition of dead plant debris does not take place in functioning peatlands due to the anaerobic, wet and acidic environment, which ultimately leads to the formation and accumulation of peat. In this way, peat growth forms up to 10-meter-thick sequences (Strack et al., 2008) with a growth rate of approximately 0.5 – 1.0 mm/year, depending on peatland type, vegetation and climate (Zhang, 2013). Pristine European peatlands accumulate on average up to 7.8 t CO_2 ha^{-1} yr^{-1} (mean value, derived from Weldon et al., 2016; Strack et al., 2008; Byrne et al., 2004; Joosten and Clarke ,2002). The exceptional significance of peatlands for climate thus is not only characterised by their balance of climate related gases, but also by their major role in accumulating and storing carbon dioxide and therewith climate change mitigation (Parish et al., 2007).

An estimated 600 000 km^2 of intact (peat-forming) peatlands were present in Europe until the 17th century (Succow and Joosten, 2001). Currently, the extent of peat and peat-topped soils covers only around 290 000 km^2 (Montanarella et al., 2005) equalling a loss of the size of Italy. Significant European peat deposits are found in northern Europe with Scandinavia, Poland, Russia and the Baltic countries accounting for more than 70% of total European peatlands. Other deposits of interest can be found in northern Germany, Denmark, the Netherlands, Great Britain and Ireland (Joosten, 2009; Montanarella et al., 2005). In 2008, all European peatlands with a minimum peat layer of 30cm covered approximately 504 608 km^2 (Joosten, 2009), equalling 5.3% of the total land area. Of these, 219 637 km^2 are currently drained and used for agriculture, forestry, urbanisation and peat mining (Joosten, 2009), accounting for 5% of the total anthropogenic emissions (Wetlands International, 2014).

Industrial peat mining, and draining for agricultural and forestry remove the conditions which are necessary for peat conservation and lead to the emission of peatland related climate forcers, mainly CO_2, N_2O and CH_4. Drainage of peatland sets the process of peat mineralisation to carbon dioxide in motion. The burning of fuel peat, which is common in Finland, Sweden, Russia and Ireland, releases the stored carbon dioxide directly to the atmosphere. Additionally, around 100 peatland fires take place on degraded and abandoned peatlands annually (Wetlands International, 2016), resulting not only in extreme releases of CO_2 but also causing severe hazards to local communities.

Currently the majority of European peatlands are in a state of continuing degeneration. Drainage leads to a continuously proceeding change of peat. Previously reduced cycles of matter get activated, carbon dioxide and nutrients get released and organisms adapted to nutrient rich environments get favoured. In agricultural land use, subsidence, shrinkage, mineralisation and erosion necessitate new drainage. As a result, peatlands used by

agriculture turn more and more into fallow lands (Strack, 2008).
There is a broad consensus that restoration of peatlands can make a significant contribution to climate protection and nature conservation. Policies and conventions about wetland protection exist at all levels of government, and align with global climate change conventions (Ramsar Convention, 2003; Wetlands international, 2003). The task of climate conventions is nowadays to find out whether or not peatland restoration or rewetting is reliable and reasonably practical.

The aims of this thesis were to investigate whether large-scale re-establishment of natural conditions in degraded European peatlands might promote the natural ability of peatlands as major carbon sinks in the context of climate change mitigation. This shall not only be based on emission factors but also on cost-benefit analyses and technical as well as governmental feasibility.

2) Methods

Between October and December 2016, the databases and digital libraries EBSCO, SCOPUS, Web of Science and JSTOR as well as key journals such as Mires and Peat and Telma were searched for the desired literature. Additionally, Google was searched for related documents, statistics and official webpages from political, regulatory, national and communal levels. Books, booklets and presentation files from official peatland initiatives and political frameworks were also taken into account. Moreover, the reference lists of the selected resources were searched to identify additional suitable references that were not discovered by the database search. During the search, no reports or literature studies specifically dealing with the question and subsequent calculation of this thesis were identified.

Keywords in search engines included: peatlands, wetland, peat, rewetting, restoration, climate change, climate forcers, Kyoto protocol, restoration techniques and a wide variety of further related terms.

Criteria for selection of the literature:

- Published in English, German, Swedish, Norwegian, Danish or Dutch
- For general background information: literature published since 1980
- For governmental, statistical and methodological information: literature published since 2008
- Studies including identifiable qualitative data
- Authors who were acknowledged qualified professionals within the topic
- Official legislation, framework and guideline documents on international and national levels
- Project descriptions with detailed information about motivations, experiences and results

Exclusion criteria:

- Literature without identifiable qualitative or quantitative components
- Documents including permanent repetition of the same authors, lacking own contributions
- Literature focusing on other climatic zones or data from non-European countries
- Unclear or insufficiently presented studies

3) Background information

3.1) Peatland characteristics and terminology

Peatlands are part of wetland ecosystems. They have a positive balance of materials due to an inhibited microbial decomposition of dead organic material and are characterised by accumulation of dead plant debris under anaerobic processes and conditions of permanent water saturation. This organic material is referred to as *peat* and areas with a soil of peat are referred to as *peatland* - these vary substantially in type and definition (see box below). Besides water saturation, peatlands are characterised by subsequent steps of vegetational processes. A specific vegetation develops on them, which after their decay leads to an upward growth of the soil surface due to accumulation of the dead plant debris.

Peat formation in mires are settled, i.e. in situ, accumulations of incompletely decomposed plant material. Generally, dead plant debris is exposed to processes of mineralisation and humification, which are controlled by microorganisms (Vepraskas and Craft, 2016). The rate of decay depends on the temperature, availability of oxygen, chemical composition of the plant material and the activity of microorganisms (Dierßen and Dierßen, 2008). Climate is the most important factor in peat formation as it determines the necessary water conditions, plant growth and decay rate. Under aerobic processes, decomposition proceeds relatively fast and CO_2 is released. However, the low oxygen content under water-saturated ground leads to either very slow or no decompositional processes at all, at least in the lower soil horizons. Other important factors that contribute to peat formation are high amounts of persistent organic materials in dead plant remains as well as a lack of soil animals (Rydin and Jeglum, 2013). Consequently a small amount of biomass remains in the soil and lead to a growth of mires at a rate of approximately 0.5 – 1.0 mm/year, with variations depending on peatland type, vegetation and climate (Zhang, 2013). Most existing peatlands formed in the last 10.000 - 15.000 years, and accumulated peat up to a thickness of 5 – 10m, depending on conditions (Andriesse, 1988). As undrained peat consists of 85 – 95% water as well as dead plant remains of which at least 50% is carbon (Schumann and Joosten, 2008), peatlands are natural carbon sinks of utmost importance for carbon sequestration and climate regulation.

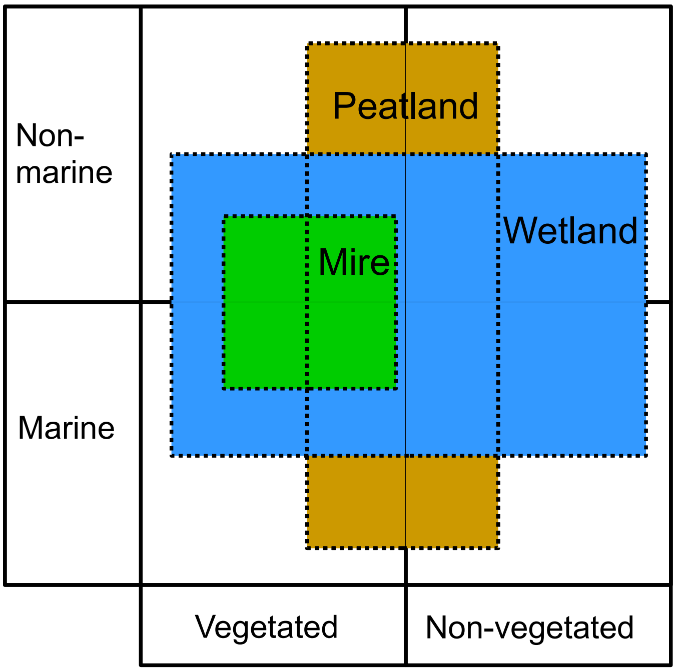

Fig. 3.1: The relationships between mire, peatland and the four principle categories of wetland (modified from Bragg and Lindsay, 2003)

3.2) Peatland types

Not all peatlands are the same - they can be defined by various factors.
The historical method of classification was very simple. Peatlands were called either „bogs“ or „fens“ - this classification was primarily based on their topographic location. **Bogs** were usually situated higher than their surrounding area, which is often a body of water (Dierßen and Dierßen, 2008). Bogs were the sites predominantly used for peat extraction, as they are relatively dry compared to fens (Rydin and Jeglum, 2013). **Fens** on the other hand were situated in landscape depressions and left open water back when peat extraction ceased (Joosten and Clarke, 2002). In contrast, the modern division is based on the source of water. When a mire is controlled by water that has been in contact with mineral soil or bedrock (Schumann and Joosten, 2008) it is referred to as a **geogenous mire** or even **bog**. Mires that are exclusively supplied by nutrient-poor and relatively acidic precipitation in the form of rain or snow are called **ombrogenous mires** or **fens**. A transitional form between bog and fen is called a **poor fen** – the upper layer of peat in these mires is not any longer fed by groundwater whereas its nutrient content and pH value are still above those of bogs/ombrogenous mires. The development of vegetation is higher but mosses such as *Sphagnum* also occur (Rydin and Jeglum, 2013).

Sub-categories of mires can be made by examining ecological factors such as occurring vegetation, the nutrient availability and acid-base saturation (PH value). This **ecological mire typology** is more descriptive as it includes the respective site conditions as a function of pH measurements, nutrient availability as well as primary production. The latter factors are indicated by the C/N ratios of the topsoil and plant material (Schumann and Joosten, 2008). The thee classifications of ecological mire types are named after their trophic conditions (nutrient availability) and referred to as **eutrophic, mesothrophic and oligotrophic** (Tarnocai, 2006).

Terminology : Selected terms of wetland used in this thesis

Wetland:
An area in which soils are saturated by water at a sufficient frequency and time span to result in wet and anaerobic conditions, therewith providing a habitat for hydrotrophic vegetation.
May be marine, coastal, inland or anthropogenic.

Peatland:
An area covered by a naturally grown peat layer, independent on current vegetation and status of peat formation. Includes areas where peat accumulation has stopped. May also include mire complexes (several types of peatland in one area). In some definitions, a minimum peat depth of 30 centimetres is required.

Peat:
An accumulation of incompletely decomposed dead plant material that has been formed in-situ under anaerobic and water saturated soil conditions. Contains at least 65% organic matter.

Mire:
Active wetlands or peatlands, where peat is currently being formed. Usually includes bogs and fens.

Bog:
A mire dominated by mosses that receives water mainly by precipitation with only small amounts of water from surface inflow. Usually lies higher than its surrounding area, which is often a body of open water. Bogs form in areas of acidic and nutrient-poor soil and are characterised by low alkalinity.

Fen:
A mire dominated by grasses, sedges, reeds, shrubs or forests which receives water by precipitation and surface inflow as well as groundwater inflow. Usually lies in landscape depressions and are lower than their surrounding area. Fens are characterised by alkalinity and moderate to high nutrient contents.

There are more comprehensive classification systems available that divide the peatland types named above into systems, subsystems and classes. This further division is not of importance for this thesis and thus will not be handled as it differs from country to country and is not a unifying definition of wetlands. The broadest definition is offered by the Ramsar Convention of Wetlands of International Importance and can be downloaded at:
http://archive.ramsar.org/cda/en/ramsar-documents-guidelines-strategic-framework-and/main/ramsar/1-31-105%5E20823_4000_0__

Note: Wherever the term peatland is used in this thesis it also includes mire without additional mention.

Box 3.1: Based on Mitsch and Gosselink (1993), Schumman and Joosten (2008), Central European University (n.d.), Čížková (2013)

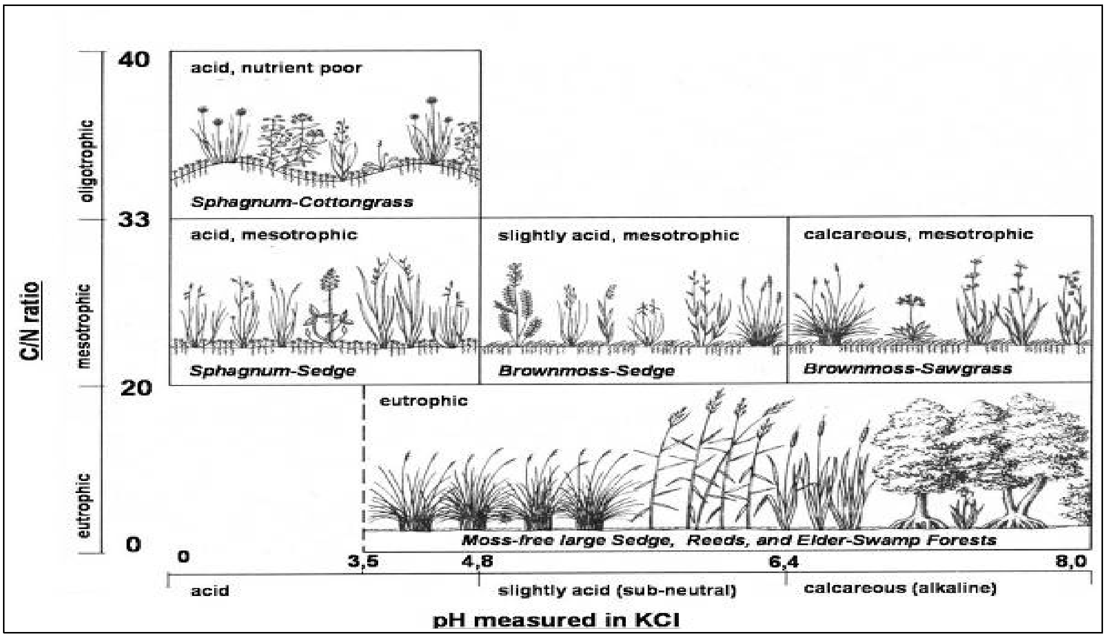

Fig. 3.2: Ecological mire types for Central-Europe (taken from Succow and Joosten 2008)

The sub-categorisation into **hydrogenetic mire typology** is carried out on the basis of hydrological characteristics (water quality, water cumulative flows, seasonal variations of the water table) of the mire and its catchment area, geomorphological features (relief), climatic (temperature, precipitation, evaporation) and geological (bedrock) conditions as well as vegetational (peatforming vegetational cover) conditions of the area (Joosten and Clarke, 2002). The history of development (transition from glacials and interglacials) is also included in this distinction as it resulted in growth or stagnation of the mires. A first classification can be made based on the source of water – **ombrogenous** or **geogenous** mires (Čížková, 2013), followed by further division into hydrogenetic mire types, which can be either passive – i.e. laying horizontally in the landscape (**topogenic mires**) or active – i.e. having a essential water flow due to their sloped surface (**soligenic mires**) (Keddy, 2010). The definitions of these mires can be found in the box below.

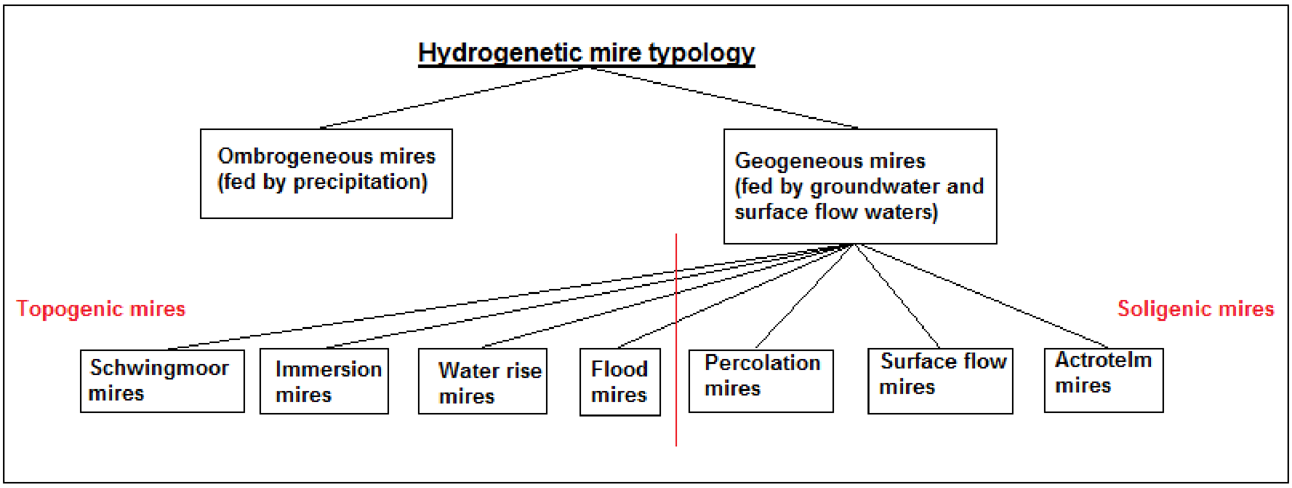

Fig. 3.3: Hydrogenetic mire types (own illustration)

As water plays the central role in the development of peat, the distinction within the hydrogenetic mire topology is of utmost importance. This refers to whether peat developed in open water (**terrestrialisation**) or accumulated directly over a paludifying mineral soil in previously drier areas without a prevenient entirely aquatic phase (**paludification**) (Vitt, 2006).

Schwingmoor mires:
One type of terrestrialisation mire. Form when open water bodies become overgrown with floating mats of vegetation that later on form peat. The formation of peat is completed when the water is completely silted up. A secondary type of mire (e.g. a ombrogenic mire) might form afterwards.

Immersion mires:
The second type of terrestrialisation mire. Immersion mires form when peat accumulates as peat clay underwater on the bottom of a body of open water. The formation of peat is completed when the water is completely silted up. A secondary type of mire (e.g. a ombrogenic mire) might form afterwards.

Water rise mires:
Form when the water level rises above drier surfaces and therewith consequently leads to water accumulation in depressions which later leads to peat formation. The causes for rising groundwater levels are varied.

Flood mires:
Areas that periodically get flooded can develop flood mires. Peat in these locations is characterised by typical layers of decomposition that form in periods of dry and non-flooded conditions by oxygen influx. Beside that, typical features of flood mires are mineral substances that have been carried in during flooding.

Percolation mires:
Characterised by year-round high water levels and nearly always linked to substantial groundwater flow. Peat from these mires is macropore, absorbent and can store large amounts of water.

Surface flow mires:
Typical surface flow mires include *blanket bogs*, *hill slope mires* and *spring mires*. They are fed by entirely precipitation, near-surface runoff water or artesian groundwater (Schumann and Joosten, 2008). Due to the periodic fluctuation of water level the peat is partially decomposed. This leads to a lower porosity and resulting permeability of the soil. The mires are hence not flowed through but rather show surface water flow.

Acrotelm mires:
In acrotelm mires, the bulk of water flows through the upper peat layer (the acrotelm), which shows a very distinct undecomposed peat cover. Permeability declines with depth and peat formation is very effective in these mires. The *raised bog* is a typical example of this type.

Box 3.2: Definitions of hydrogenetic mire types based on Schumann and Joosten (2008), Joosten and Clarke (2002).

3.3) The distribution of peatlands and peatland loss in Europe

Accurate estimates of European peatlands are not easily to provide. Information from the particular geological or geographical surveys vary considerably, and there is no common standard terminology about the definition of peatland categories. Therefore, data about peatland estimates are seldom in agreement (Joosten and Clarke, 2002). However, focus on the distribution of peatland in Europe has grown over the last 20 years and estimates have become more accurate over time. Databases such as the Global Peatland Database (IMCG, Joosten 2012), European Soil Database (http://esdac.jrc.ec.europa.eu/) as well as the Map of Organic Carbon in Topsoils of Europe (Jones et al., 2005) assembled beneficial data to provide international and country based data with similar background definitions. In 2002, Joosten and Clarke defined peatland as „sedentary accumulated material consisting of at least 30% (dry mass) of dead organic material" with a depth of at least 30cm (Joosten and Clarke, 2002).

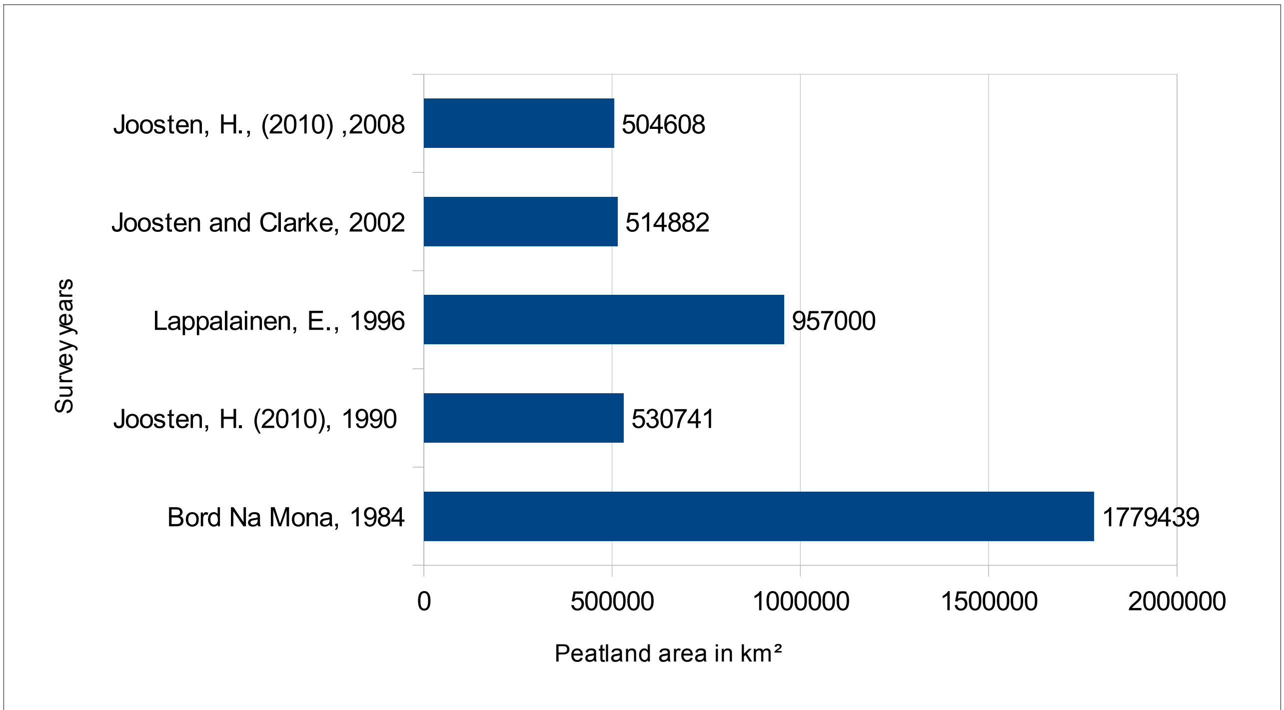

Fig. 3.4: Estimates of European peatland area distribution in km² derived by the surveys shown (own illustration)

In Europe, accurate estimates of peatland extent are available from the beginning of 1990s. Some historical data is also available but this has a higher degree of uncertainty due to the definitional problems and limitations named above, as well as practical problems due to the lack of modern technical devices and resources. Additionally, most estimates did not distinguish between different types of peatland. The data presented here are based on several peatland area estimates in Europe from different sources and survey years shown in figure 3.4. It is obvious that the estimates made by Bord Na Mona in 1984 as well as those from Lappalainen (1996) highly differ from those of Joosten made for Wetlands International. The Bord Na Mona survey estimated the area of peatlands in Europe more than three times higher than in Joosten's study. Lappalainen's calculations are lower, but still far above the average, with an estimated peatland area of around 960.000 km². Due to this uncertainty in evaluation, I will introduce the generally accepted data published by Joosten (2009) and Joosten and Clarke (2002) as this data is derived from standardised databases and thus is more reliable. In 1990, European peatlands covered an area of about 530.000 km² which equals about 5.6 % of the total European area. Parish et al. (2007) stated that this amount is about 12.4 % of the global peatland area. When compared to the most recent study by Joosten (2009), it become apparent thay European peatlands lost about 26 000 km² - which is about the size of Macedonia - between 1990 and 2008. Historical data show that estimated 600.000 km² of peatland were present in Europe until the 17th century. Now, the extent of non-drained and intact peatlands covers only about 290.000 km² (Montanarella et al., 2005).

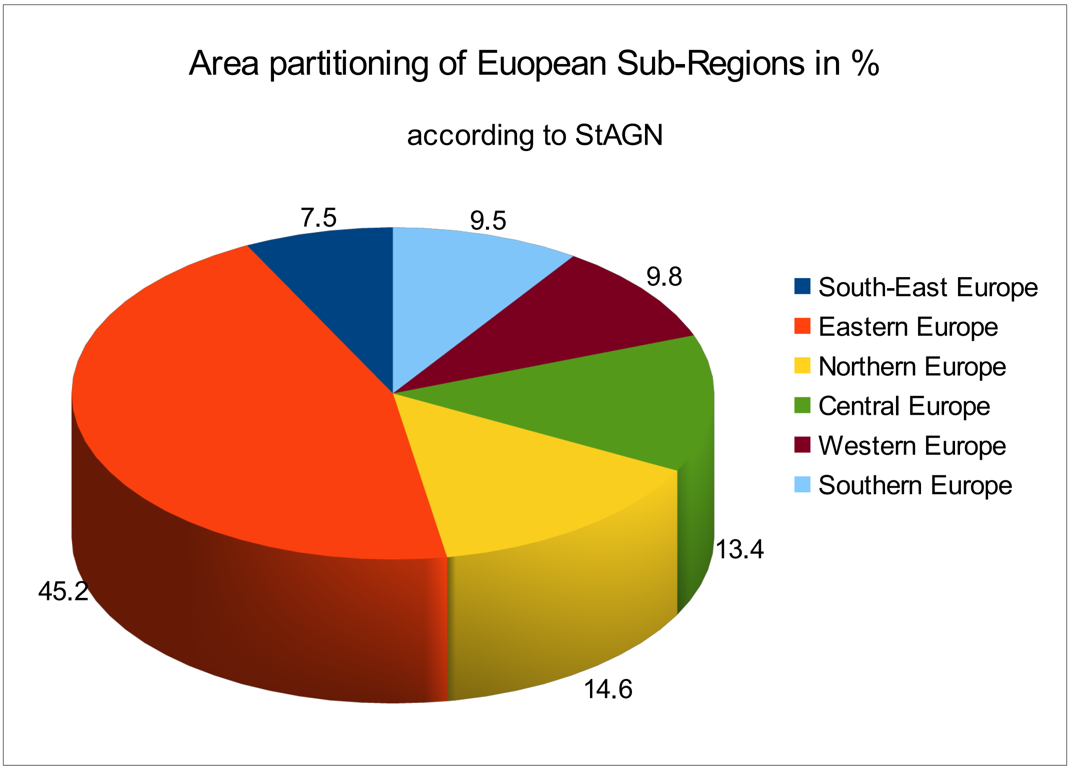

Fig. 3.5: Area of European Sub-Regions in % (own illustration, data derived from Joosten , 2009)

The table in appendix I shows estimates about peatland area in km² for each European country. To get a better overview about major European peat deposits as well as the losses per area, I subdivided the European Countries into sub-regions according to the Permanent Committee on Geographical Names (Ständiger Ausschuss für geographische Namen - “StAGN”) definitions.

As figure 3.5 shows, Eastern Europe accounts for nearly the half of the total European area, followed by northern and central Europe which account each for 14.6 respective 13.4 percent. Western, southern and south-east Europe are of similar size with 7.5 to 9.8 % of the total European area. In total, Europe lost about 260.000 km² of peatland between 1990 and 2008 and current surveys estimate a rate of peatland loss during the period 1990 – 2015 of about 350.000 km² (Vepraskas and Craft, 2016). Because peat formation is so closely related to climate, it is not surprising that south-east and southern Europe have the smallest areas of peatlands (fig. 3.6). Positive balances between decay and production of organic matter as well as net precipitation and evaporation are essential for peatland formation, and these conditions rarely occur in the warmer parts of Europe. The lack of suitable land, water storage possibilities and low precipitation account for this fact (Parish, 2007). These areas (1760 km² resp. 274.5 km² in 2008) have been relatively stable in size and play only a minor role in the European climate debate on peatland. Western and central Europe account for 9.6 respectively 6.6 % of the European peatlands, which is a considerable area relative to their size. The peatlands of central Europe have assumed particular importance in European and global peatland conventions due to their preservation potential of different peatland types including biodiversity (Bragg and Lindsay, 2003; Tanneberger and Wichtmann, 2011). In matters of the geographical and climatic location it is plausible that northern Europe and the European part of Russia have the most considerable areas of peatland.

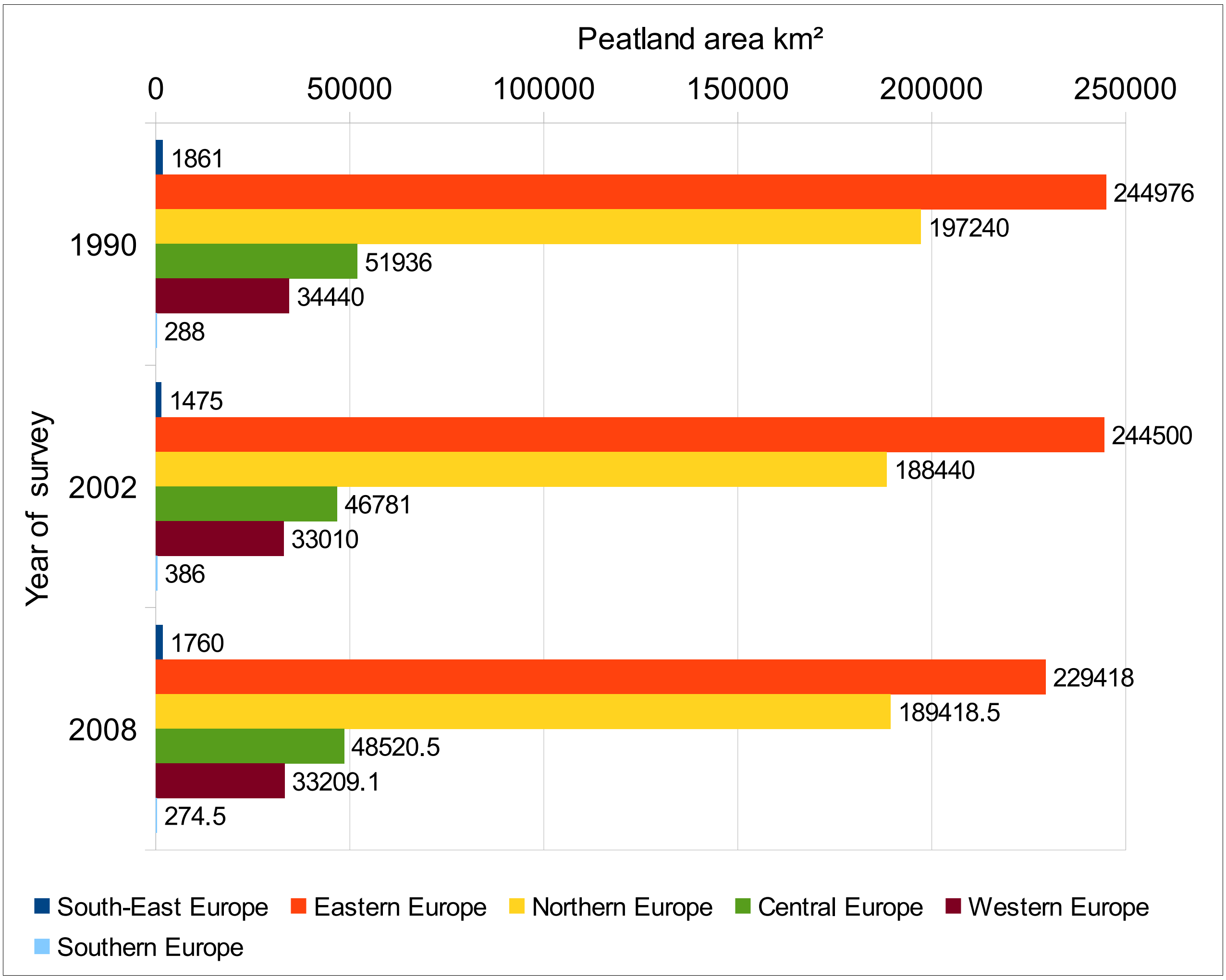

Fig. 3.6: Peatland distribution depending on region (own illustration, data derived from Joosten , 2009)

With current areas of around 190.000 km² and 230.000 km² these regions provide more than 80% of the total European peatland area. Relating to the size of the Nordic countries it is a noticeable fact that only 14.6 percent of the European landarea accounts for more than 37 percent of the total European peatland. Of these, almost one-third of the peatland resources are located in Finland and more than a quarter in Sweden (Montanarella et al., 2006).

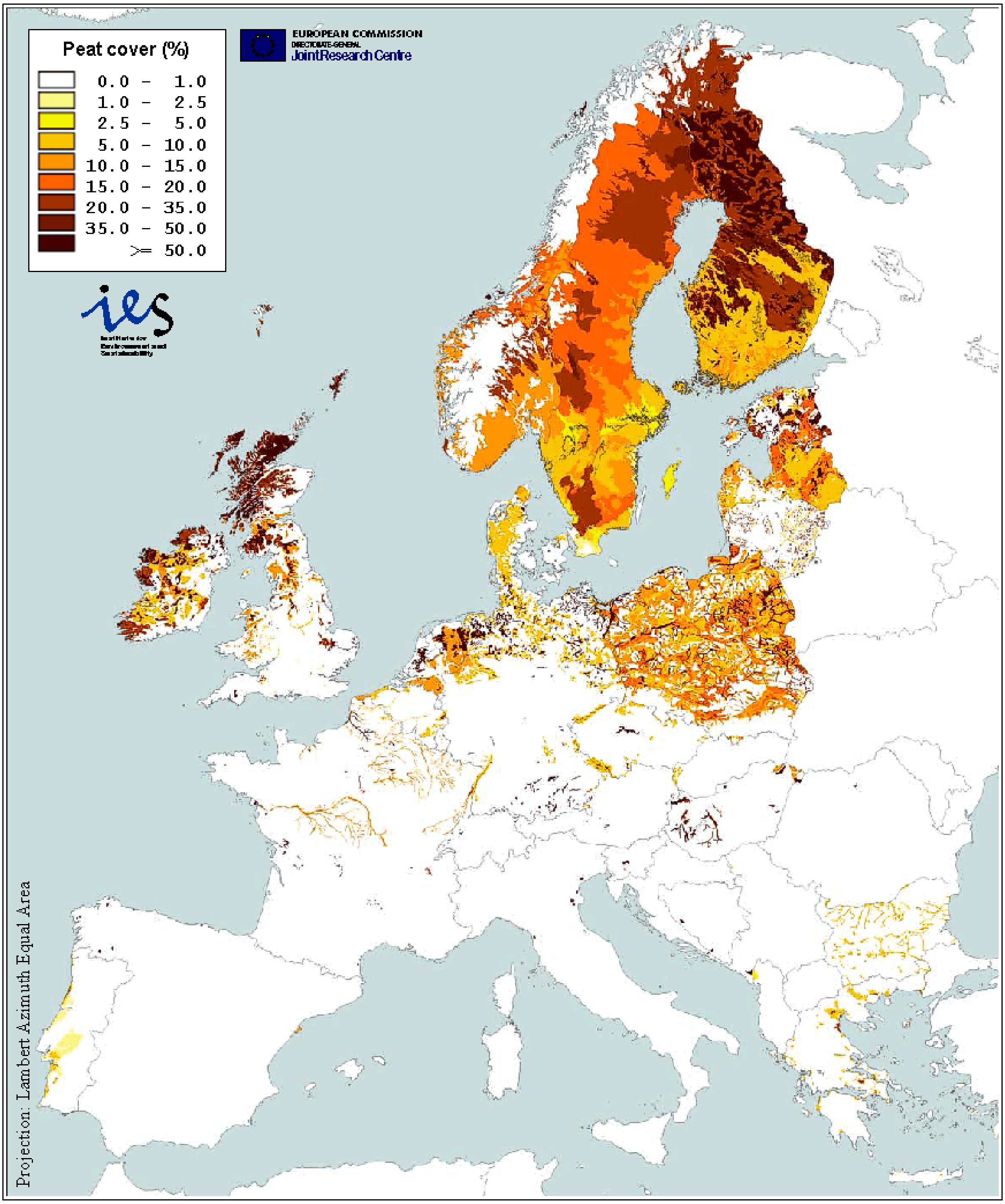

Fig. 3.7: Relative cover (%) of peat and peat-topped soils in the SMUs of the European Soil Database (taken from Montanarella et al., 2006)

Unfortunately, Europe's long cultural history, large population and climatic suitability for agriculture made it the continent with the largest loss of peatland worldwide (Joosten, 2015). Industrial peat mining and agricultural and forestry use remove the conditions which are necessary for peat conservation. Drainage of peatland sets the process of peat mineralisation to carbon dioxide in motion. In Europe, the countries with the least peatland have lost most and the general average of peatland loss is estimated to be between 50% and 99% (Coelho, 2014). Denmark and the Netherlands lie at the higher end of these estimates, having destroyed their former dominant landscape (Joosten, 2015).

The spread of mechanised agriculture and tractors since 1950 led to increasing degeneration of peatlands by drainage for agriculture and forestry. Finland for example lost almost 60% by drainage for forestry (Joosten, 2015).

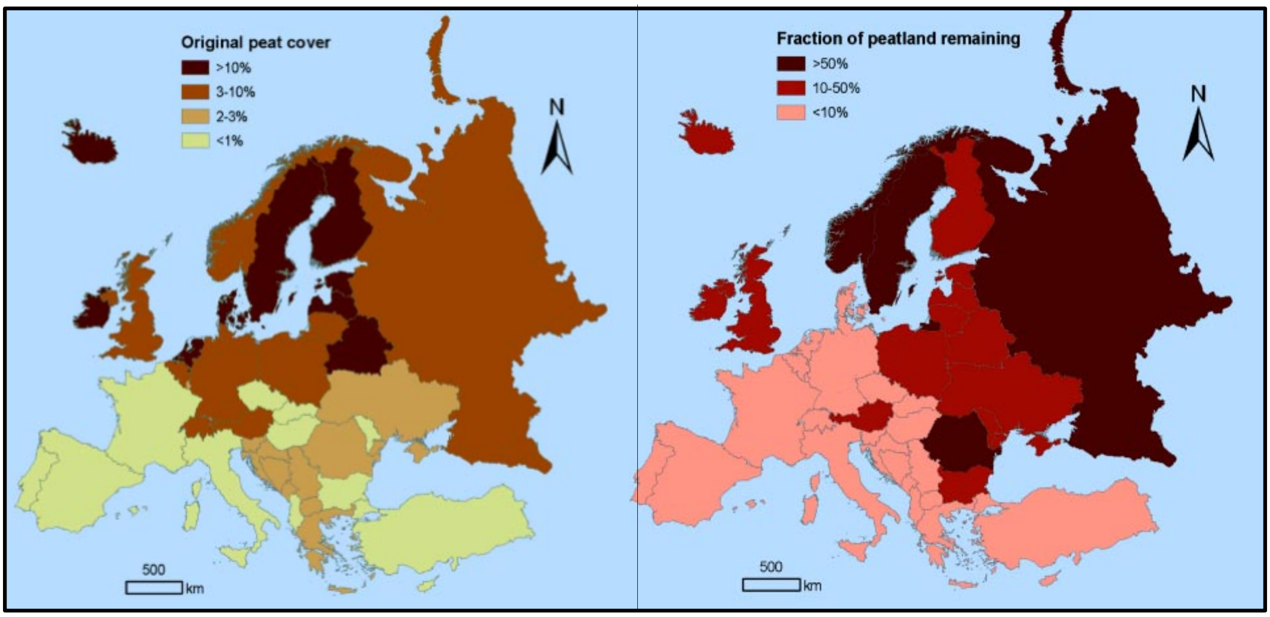

Fig. 3.8: Original and remaining peatland extent (modified from Bragg and Lindsay, 2003)

According to these estimates, only five countries still have preserved more than 50% of their original peatland in undisturbed conditions. Byrne et al. (2004) reported that only 305.000 km² of peatland are still in an undrained and peat forming condition. Other anthropogenic major threats to peatland include drainage for urbanisation and peat mining.

3.4) The importance of peatlands in the climate debate

In the course of the current climate debate, strategies of mitigation and adaption for coping with climate change are urgently sought. In this context, peatlands come into the field of vision as the definitions “peatland” and “climate” are strongly interrelated. The significant climate relevance of peatlands can be recognised by understanding the peat formation processes which lead to their function as enormous storage reservoirs for carbon dioxide.

Peatlands cover only 3% of the Earth's surface and have a volume of estimated 4 trillion m³ , but store within their layers one third of all terrestrial carbon dioxide – twice as much as all the Earth's forests (Strack et al, 2008). In Europe, peatlands cover 5.3% of the land area and degrading peatlands - mainly by drainage for agriculture, forestry, urbanisation and peat mining account for 5% of the anthropogenic emissions (Wetlands International, 2014). Peatlands are important sinks for carbon dioxide due to their high content on organic material. Year-round high groundwater tables and anaerobic conditions lead to minimised decomposition of dead plant debris (Rydin and Jeglum, 2013). In that way, peat growth forms up to 10 meter thick sequences and globally natural mires consequently remove 150 – 250 million tons of atmospheric carbon dioxide (CO_2) every year (Bragg and

Lindsay, 2003; Joosten, 2006). On the other hand, peatlands drained for intensive agriculture release 14 – 24 tons of carbon dioxide per hectare / year into the atmosphere under European climate conditions (Höper, 2007).

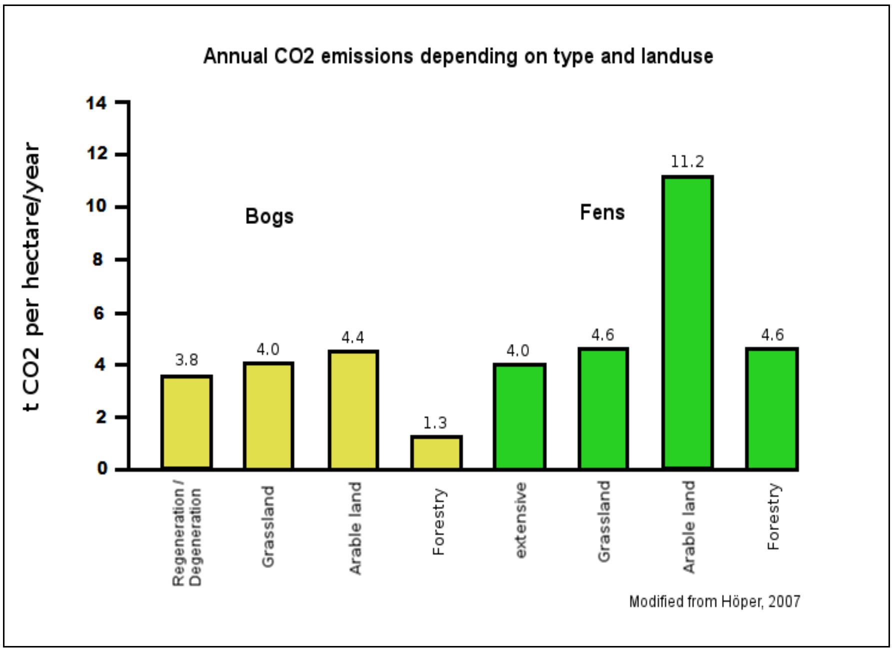

Fig. 3.9: Annual CO_2 emissions depending on type and land-use (modified from Höper, 2007)

Intensive use of peatlands leads to an increase in peat aeration. Peat aeration, decomposition and mineralisation eventually causes the accumulated organic matter to be emitted in the form of climate forcers such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Strack, 2008). Peatlands nowadays thus transform more and more from carbon sinks into carbon sources and are an important factor in the current climate debate (Höper, 2007). The intensity of anthropogenic impact, combined with the different types of peatlands and their respective hydrological circumstances lead to very differentiated research on the balance between CO_2 fixation/release as well as CH_4 production/consumption (Gorham, 1991).

To define the climate relevance of peatlands, trace gas fluxes between the atmosphere and soil have to be measured over a period of at least one year with respect to CO_2, CH_4 and N_2O. The current storage of CO_2 in active peatlands counterbalances methane emission (Trepel, 2008) which have a 23-fold global warming potential (the fifth assessment report of the IPCC assumes even more: 28-fold) compared to CO_2 (Joosten, 2015), but only a relatively short atmospheric residence time (Succow Foundation, 2010). Joosten and Couwenberg (2009) stated that “when peatlands remain wet, the peat carbon is conserved virtually forever”. At the same time, N_2O emissions decrease whereas CH_4 emissions increase (Trepel, 2009). In drained peatlands, the emissions of CH_4 decrease whereas CO_2 and N_2O emissions increase (Trepel, 2009). Particularly in peatlands drained for agriculture, emissions of N_2O are important climate forcers because nitrous oxide is 298 times more potent than CO_2 (Joosten et al., 2015) and highly available and mobile due to fertilisation (Wetlands International, 2014). Unfortunately, due to these varying circumstances, emissions of N_2O are often disregarded in studies about peatlands and their importance in the climate debate. On grounds of sustainability, peatland protection and climate change mitigation there must be procedures and agreements on the prevention of emissions from peatlands – either degraded or active. Restoration and rewetting of peatlands, sustainable agriculture and optimizing of the groundwater table are possible procedures.

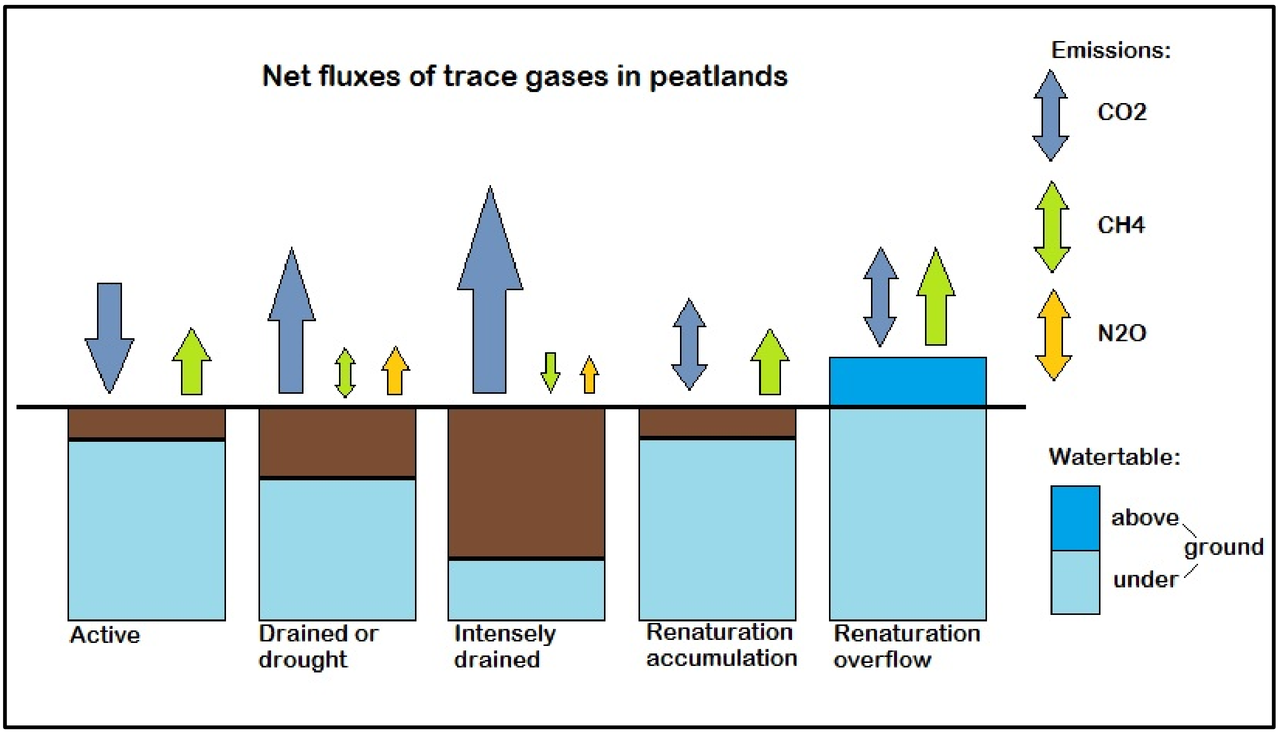

Fig. 3.10: Net fluxes of trace gases in peatlands (own illustration, modified from Freibauer et al., 2009)

The exceptional significance of peatlands for climate thus is not solely characterised by their balance of climate related gases, but by their major role in accumulating and storing carbon dioxide and therefore in climate change mitigation.

3.5) Peatland use in Europe

The present use of peatlands in Europe is for the most part restricted to three categories.

Peatlands drained for agriculture represent the most intense damage. Conversion to grasslands and arable lands require a lowering of the ground water table by drainage. The numbers of mean drainage depth reported vary somewhat, but generally mean lowering of 0.4 – 0.8 meters for grasslands and 1.0 – 1.2 meters for arable lands have been required (Byrne et al., 2004). Unfortunately, the process of drainage in combination with full-areal machinery traffic results in restricted useful life. Höper (2009) reported that due to subsidence, peatlands drained for agriculture show a height loss of 1cm (grassland) resp. 2cm (arable land) every year. This leads to an expected useful life of only 55 / 110 years (grassland / arable land) for peatlands with a mean depth of 1.4 meters and 15 / 30 years for shallow peatlands with an average of 0.6 meters (Höper, 2009). In Europe 14 % of all peatlands are currently drained for agriculture, which is equivalent to 124 490 km^2 (Joosten and Clarke, 2002).

Figure 3.11 (for country based details, see appendix II) represents the use of European peatlands drained for agriculture, forestry, peat mining or residual in percentages for each sector.

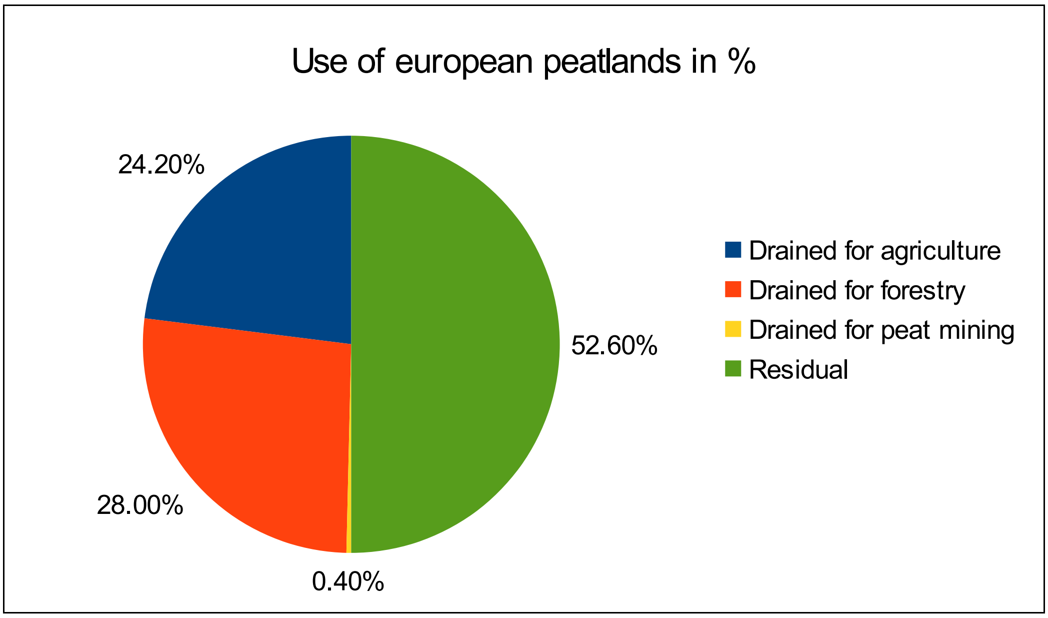

Fig. 3.11: Use of European peatlands in percentages (own illustration, based on data from Joosten and Clarke, 2002; Byrne et al., 2004, Rydin and Jeglum, 2013)

It is controversial whether forestry is included in the term agriculture or not. In this thesis, I will treat forestry independently. Particularly in Scandinavia, the Baltic countries and the European part of Russia there are vast regions of formerly undisturbed bogs and fens which have been drained for forestry. For example, one third of Finland's total land area has been classified as peatland (Lappalainen, 1996). Of these reported 94 000 km^2 (Joosten and Clarke, 2002), nearly 2/3 have been drained for forestry, with spikes in the early 1950s and 1960s-1970s (http://www.metla.fi/tutkimus/suotutkimus/tausta-en.htm (2015), accessed: 19.12.16). A prerequisite for forestry on peatlands is drainage, but some undrained managed forests have been indicated from Fennoscandia (Minkkinen et al., 2008). All other treatments (fertilisation etc.) are in accordance with ordinary forestry on mineral soils (Similä et al., 2008). Since most European forests on peatlands are now at most 70 years old, forestry management is an up-to-date topic as most forests are ready to harvest 80 – 100 years after plantation. Overall, approximately 144 000 km^2 of European peatlands have been drained for forestry of which 111 000 km^2 are located in Finland, Sweden and the European part of Russia.

Peat extraction or mining is the third category to be mentioned here. Peat mining has a long history in Europe and the use of the cut-out peat is varied. Today, peat extraction for energy is common in Finland, Russia, Sweden and Ireland (Joosten and Clarke 2002). In rural areas, peat is still often cut by hand for energy purposes but these amounts only account for minor impacts on peatland. Corresponding to the report of Peat Resources Limited (2009), peat equivalents to 3310 ktoe are mined only in Finland, Sweden, Ireland, Estonia, Latvia and Lithuania. Byrne et al. (2004) reported that Finland, Russia and Ireland together extract 14.4 million tonnes of fuel peat every year.

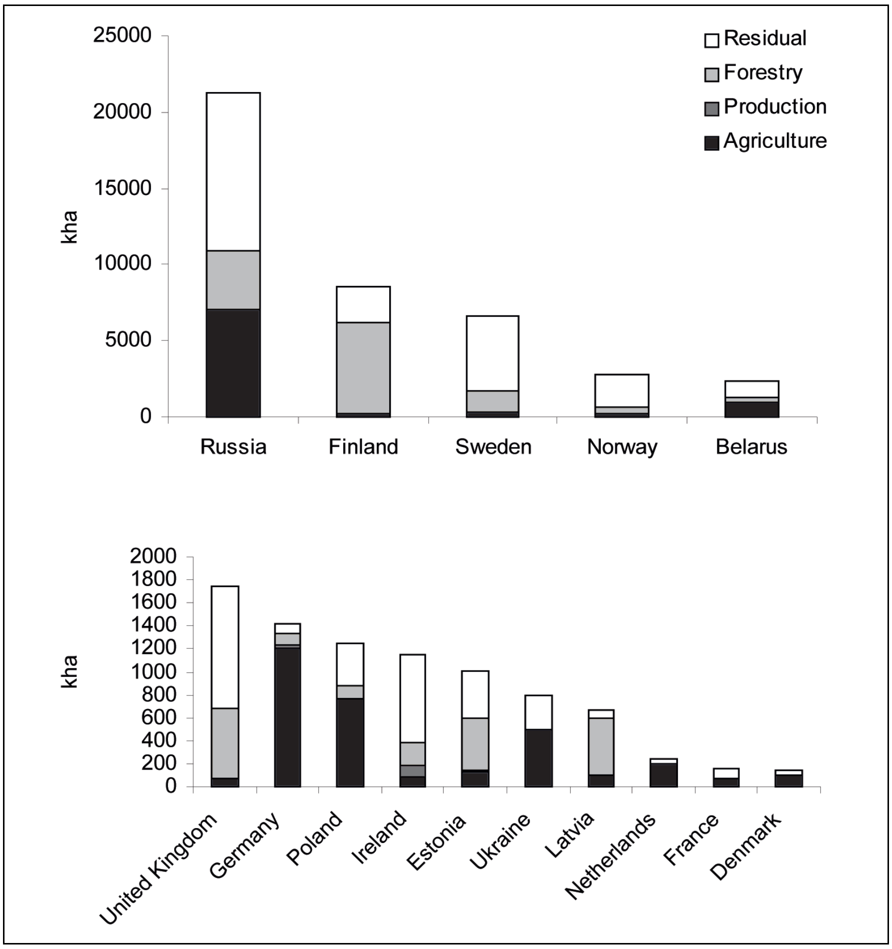

Fig. 3.12: Reported peatland areas broken into published numbers of areal use of peatlands and the residual for individual European countries (taken from Byrne et al., 2004)

To discuss peat mining in Europe in detail would go beyond the scope of this thesis, but a detailed report has been published by Paapanen and Leinonen (2005). Peat extraction for other purposes than fuel is to a greater extent associated with private gardening and horticulture. The production of peat used in horti- and agriculture declined significantly from 72.1 million m^3 to 20.0 million m^3 between 1990 – 1998 (Joosten and Clarke, 2002), but received a noticeable boost from 26.8 million m^3 in 1999 to 29 million m^3 in 2007 (Altmann, 2008). The total area of peatland in the EU member states used for industrial purposes is estimated to be around 1200 km^2 (Altmann, 2008). In addition, peat is the main component in the production of culture media and potting soil in Europe and should be reduced due to the availability of other alternative starting substances such as compost, bark mulch and wood fibres (Schmilewski, 2008). Other possibile uses for peat such as in the medical industry, as housing insulation or for absorption purposes in agriculture are negligible. While drainage for agriculture and forestry leads to a climate impact based on general behaviours of gas fluxes (see next chapter for further details), burning peat fuel releases large amounts of carbon dioxide directly to the atmosphere. The specific carbon dioxide emissions of fuel peat are on average 0.38 kg CO_2 / MWh (Quaschning, 2010). According to the aforementioned 3310 ktoe peat burned for energy, this is equivalent to 284608770.42 kWh of peat burned per year (1 ktoe = 1000 toe = 10^6 oe = 85984,5 Mwh). These annually release 108.2 kt CO_2 directly to the atmosphere, in addition to direct emissions on peatland sites through damage.

4) Peatland and climate forcers

4.1) Fluxes of carbon dioxide

There are two groups of processes within the carbon cycle that are related to the exchange of carbon dioxide in peatlands. The primary source of carbon assimilated from peatland is atmospheric CO_2, absorbed by peatland vegetation through photosynthesis (autotrophic fixation of C). The second process is the antagonistic process. This is emission as a result of soil and plant respiration (Chojnicki et al., 2010). These two different processes define the importance of peatlands and the need for peatland management, as fluxes of carbon dioxide are central to the current climate debate. These respiratory processes return directly to the atmosphere. 80 – 95% of the organic material within the acrotelm which is consumed by bacteria gets released as carbon dioxide (Dierßen and Dierßen, 2008). Some carbon which is converted to plant material within the acrotelm moves into the deeper catotelm (Joosten and Clarke, 2002). Only a minor amount of the gross primary production is thus added as peat. Processes of decomposition are not suspended, but are decelerated by a factor of 100 compared to the acrotelm (Fleischer et al., 2016). These basic processes already show that peatlands might be ambivalent in the context of anthropogenic or naturally driven gas fluxes. Considering different peatland types and the variables of location, plant communities and time periods, peatlands can act as a source or a sink of carbon dioxide.

1.) Peatlands are naturally defined to be net sinks of carbon simply by the presence of peat (Parish et al., 2007). The utilisation of this potential is one of the main driving factors to reduce atmospheric CO_2 emissions through the restoration of peatlands. In natural or successfully restored peatlands the function as a carbon sink is defined by storage potentials in the biomass, litter and peat (Joosten and Clarke, 2002). In recent times, carbon accumulation rates are suggested to be lower than in the preceded centuries (van der Linden et al., 2014) and range from 0,15 – 1,5 t CO_2 ha^{-1} yr^{-1} in Europe's boreal and temperate regions (Joosten and Clarke, 2002; Höper, 2007, Tolonen and Turunen, 1996), strongly depending on peatland type and climate as well as temporal and spatial distribution of vegetation (Chojnicki, 2010). These rates are considered to be long term accumulation rates.

2.) Peatlands also act as sources for CO_2 and contribute considerably to the current anthropogenic emissions (Abdalla et al., 2014). Reclamation of peatland by drainage for different uses is the primary process leading to degradation. Drainage or longer periods of drought lead to subsidence of the horizon between the acrotelm and catotelm (Metzger et al., 2015). Organic material then decomposes due to the occurrence of oxygen and afterwards emitted as carbon dioxide. The amount of emissions correlate with the peatland's individual water table and may turn from negative values of pristine peatlands to values of 15 – 60 t CO_2 ha^{-1} yr^{-1} for peatlands drained for agriculture, forestry or peat extraction (Byrne et al., 2004; Wichtmann, 2016). But even inundation of undrained peatlands may result in increased CO_2 emissions due to increased decomposition within the topsoil (Parish et al., 2007).

Table 4.1 gives an overview of CO_2 Emissions in t CO_2 – C ha^{-1} yr^{-1} from drained and undrained peatlands in different climatic zones and subdivided into the peatland types bogs and fens. Data is taken from different surveys (Byrne et al., 2004; IPCC, 2006; Couwenberg, 2009) and represents mean values. One should be aware of uncertainties due to the lack of provided number of study sites, but the data anyhow show strong correlations. The IPCC data for arable and grasslands show higher uncertainty. This can be explained by the high variance of peatland types and histories in areas drained for agriculture. Standardised mean values are hence relatively unpredictable. The general trend shows that pristine bogs accumulate more carbon than pristine fens. On the other hand, temperate peatlands accumulate more carbon dioxide than boreal peatlands, but also emit more. Despite a lack of more reliable data, it is obvious in this table that accumulation and emission of CO_2 is primarily a function of climate.

Peatland type	Climate zone	Land use	IPCC (2006)	Couwenberg (2009)	Byrne et al. (2004)
Bogs*	Temperate	Pristine (Poland)			- 2
	Temperate	Pristine			- 0.4
	Boreal	Pristine			- 0.49
		Forestry	0.68		0.4
		Arable land (drained)	10.0 +/- 90 %		4.09
		Grassland (drained)	10.0 +/- 90 %	5.5	4.12
		Peat mining, rich soil	1.1	1.9	
		Peat mining, poor soil	0.2	1.9	
Fens*	Temperate	Pristine			0.71
	Boreal	Pristine			0.2
		Forestry (drained)	0.16	1.75	1.1
		Arable land (drained)	5.0 +/- 90 %	6.8	4.4
		Grassland (drained)	5.0 +/- 90 %	2.6	2.35
		Peat mining, rich soil	1.1	6.8	1.75

Tab. 4.1: CO_2 Emissions in t $CO_2 – C$ ha^{-1} yr^{-1} from drained and undrained peatlands. Asterisked terms to only relate to the data from Byrne et al., 2004

4.2) Methane fluxes

Methane is also known as “swamp gas” which already points to its connection with wetlands. Methane emissions can - remarkably - sometimes be observed as fen fires. Methane is the second most important climate forcer in the current climate debate and has a 23-fold global warming potential (the fifth assessment report of the IPCC assumes even more: 28-fold) compared to CO_2 (Joosten, 2015) but only a relatively short atmospheric residence time of approximately 12 years (Joosten and Clarke, 2002; Michael Succow Foundation, 2010). It currently accounts for 10.6% of all emissions within the EU-28 (European Environment Agency, 2016). The formation of CH_4 is caused by anaerobe methanogenic bacteria (Couwenberg, 2009) in the course of decomposition of organic material. This process is restricted to the anaerobe subsoil in peatlands. As long as the water table does not reach the surface, methane is consumed by methanotrophic bacteria and consequently oxidised to CO_2 during its ascendency through the upper aerobic topsoil (Fechner and Hemond, 1992). These bacteria are most frequent in the water table horizon (Granberg et al., 1997). Methane can reach the atmosphere through transportation in gas bubbles through the water column (ebullition), by transport through the aerenchyma of vegetation (Harpenslager et al., 2015) or by molecular diffusion through soil or water (Parish et al, 2007). The latter process is relatively slow and most common in drained peatlands. Contrary to methane emissions is the consumption by oxygen to form carbon dioxide. Oxygen reaches the subsoil via the root system and oxidizes methane to carbon dioxide. In peatlands, the water table and the occurring plant communities thus are the primary factors that define the ratio of emitted CO_2 and CH_4. Optimum conditions for methane productions are temperatures between 20 – 25°C (Parish et al., 2007). Below -5°C no significant methane production occurs (Couwenberg, 2009), so the thawing of northern Europe's permafrost wetlands should be in focus for further surveys regarding to methane emissions.

Peatland type	**Region**	**Land use**	**Couwen-berg (2009)**	**Pitkäinen et al. (1999)**	**Byrne et al. (2004)**	**Joosten & Clarke (2002)**
Bogs	Finland	Pristine (dr.)		60.2 – 79		
	Sweden	Pristine	24		37.5	0.8
	Boreal	Forestry (dr.)	8.6 – 30		20	
		Cropland (dr.)			0	2 – 21
		Grassland (dr.)			2	
		Peat mining			17.3	
	Europe	Drained	0.2			
	Temperate	Pristine	122		174	
Fens	Finland	Pristine		142 – 197		
	Boreal	Pristine	123		120	
		Forestry (dr.)			1	- 0.5 – 5.0
		Cropland (dr.)			- 0.2	
		Grassland (dr.)			0.4	
	Temperate	Pristine	50 – 170		142	
	Temperate	Grassland (dr.)				- 1.4 – 3.5

Tab. 4.2: CH_4 Emissions in kg CH_4 - C ha^{-1} yr^{-1} from different peatlands, comparison between the references provided in the table

Table 4.2 summarises some of the data available for methane fluxes in European boreal and temperate bogs and fens. Interestingly, drained fens seem to emit less methane than drained bogs and provide the function as a potential sink for atmospheric methane. Couwenberg (2009) states, that drained peatlands only have minor CH_4 emissions. According to the data provided here, increasing CH_4 emissions have been observed in pristine bogs and fens as well as in peatlands after rewetting or inundating (Parish et al, 2007; Hendriks et al., 2007). Therefore it must be discussed whether topsoil removal might be reasonable and practical as a mitigation strategy to prevent climate warming through methane emissions from restored peatlands. Harpenslager et al. (2015) reported that methane emissions had been reduced by 99% after topsoil removal. But in the discussion about methane as a climate forcer, it should always be considered that CH_4 has a very short atmospheric lifetime and its global warming potential is highly dependent on respective time horizons (Byrne et al., 2004).

4.3) Nitrous Oxide emissions

Particularly in peatlands drained for agriculture, emissions of N_2O are important climate forcers due to the fact that nitrous oxide is 298 times more potent than CO_2 (Joosten, 2015), having an atmospheric lifetime of approximately 120 years (Joosten and Clarke, 2002). Emissions of nitrous oxide are a part of the natural nitrogen cycle in peatlands. Microbial decomposition of organic nitrogen compounds in peat as well as biological nitrogen fixation produces ammonium which in turn oxidizes by nitrification to nitrogen oxide (Vepraskas and Craft, 2016). The reduction of nitrogen oxide to elementary nitrogen (N_2) is called denitrification and is caused by another group of soil microorganisms. Nitrous oxide (N_2O) gets released if the final step of denitrification was not performed, which could occur in the case of a surplus of nitrogen oxides due to fertilisation (Höper, 2011). Due to low nitrate concentrations, emissions of N_2O in pristine mires are low (Joosten and Clarke, 2002) even though anaerobic and acidic conditions favour denitrification (Parish et al., 2007). Trepel (2000) reports less than 3kg of N per hectare and year for pristine or rewetted peatlands. Martikainen et al. (1993) reported that estimations of N_2O emissions from all Finnish pristine peatlands are approximately 200 tons which is assumed to be negligible.

Peatland type	**Region**	**Land use**	**Couwen-berg (2009)**	**Joosten and Clarke (2002)**	**Byrne et al. (2004)**
Bogs	Finland Boreal Boreal Boreal Boreal Boreal Temperate	Pristine Pristine Forestry (dr.) Cropland (dr.) Grassland (dr.) Peat mining Pristine	 0.1 – 0.6 6.8	0.04 0.0 – 0.2 0 0.04	 0 0.04 0 0.1 0.4 - 0.01
Fens	Finland Boreal Boreal Boreal Temperate Temperate Germany Germany Germany	Pristine Pristine Forestry (dr.) Grassland Forestry (dr.) Cropland (dr.) Rewetted Pristine Grassland (dr.)	 0.6 – 6.4 5.8	0.04 12 – 5.0 - 0.7 – -0.2 0.6 – 1.2 0.6 – 16.0	 0.12 1.05 5.05 11.61

Tab. 4.3: N_2O Emissions in kg N ha^{-1} yr^{-1} from different peatlands, comparison between the references provided in the table

Drainage of peatlands may lead to higher emissions of up to 30kg of N per hectare per year highly depending on the water table horizon (Trepel, 2000). Emission factors of peatlands drained for peat mining are controversial. Results of the IPCC report (2014) have shown that drained peatlands are a moderate source for N_2O, whereas other surveys indicated that emissions showed a tendency towards zero (Wilson et al., 2016). Peatland management such as rewetting or flooding does reduce N_2O emissions by re-establishment of unfavourable anaerobic conditions for denitrification (Couwenberg, 2009). As mentioned above, a surplus of nitrogen oxides in the soil, as occurs in intensively used and fertilised agricultural areas, is of utmost importance for emissions of nitrous oxide (Parish et a., 2007). The relationship between external supply of nitrogen and emissions of nitrous oxide is complicated and highly dependent on the type of fertilizer and fertilizer application dates (Couwenberg et al., 2008). Peatlands used for agricultural purposes account for the majority of European N_2O emissions and the IPCC report (1996) accepts that in general around 2.5% of the applied fertilizer is eventually released to the atmosphere as nitrous oxide. However, even restoration of former drained and fertilised peatland, e.g. as in mires used for forestry in Finland, resulted in high emission rates of N_2O (Fleischer et al., 2016) which shows that emissions of nitrous oxide from heavily fertilised soils cannot simply be compensated by restoration. Further studies are expected to deal with this problem, as restoration of peatlands as a function of climate change mitigation and peatlands drained for agriculture are closely associated with each other.

4.4) Managing emissions

There are many approaches to managing emissions of climate forcers from degraded peatlands, but it is commonly accepted that rewetting of drained peatlands lead to reductions of carbon dioxide and nitrous oxide emissions (Beyer and Höper, 2015; Harpenslager et al., 2015; Couwenberg, 2009; Wilson et al., 2016; Byrne, 2004; Höper, 2011; Parish et al., 2007). It is debated whether inundation is beneficial for the purpose of promoting the formation of a carbon sink or not (Beyer and Höper, 2015; Parish et al., 2007). One should mention that especially during the first years after rewetting, emission factors for CO_2 could alternate between positive and negative before the final regulation of peatlands as carbon sinks (Wilson et al., 2016, Joosten and Clarke, 2002). In addition, a survey by Pluchon et al. (2014) found that especially rapid paludification leads to temporary global warming. As peatlands are mostly used for agriculture, it is important to avoid ploughing, especially the ploughing up of grassland. This management itself would account for the reduction of 152 000 t of CO_2 per 1000 ha (Höper, 2011). But rewetting not only promotes the formation of carbon sinks. It has been observed that emissions of nitrous oxide were not detected in these areas (Couwenberg, 2009). But as N_2O emissions from peatlands are hard to generalise, the main contributions in preventing them can be found in promoting sustainable agriculture. Rethinking fertilisation techniques is the key to long time prevention of nitrous oxide emissions. But as rewetting of peatlands seems to solve climate concerns about CO_2 and N_2O, it is strongly correlated to an increase of CH_4. Significant methane emissions occur in water saturated soils, especially in the topsoil. It is therefore suggested that successful peatland management should include either keeping the water table below -10cm / -20cm (Couwenberg, 2009) or removing the topsoil of the area (Harpenslager, 2015). The latter technique has resulted in a reduction of 99% of the net methane emission rates as Harpenslager et al. (2015) stated in their survey. All in all, inundation should be avoided in order to keep methane emissions in rewetted peatland low. A well optimised water table (Joosten and Clarke, 2002) and eventually very mild drainage (Byrne, 2004) might be prerequisites for this scenario.

5) National and international policies and conventions on climate change mitigation through peatland restoration

5.1) International policy frameworks

UNFCCC and the Kyoto protocol

The United Nations Framework Convention on Climate Change (UNFCCC) was enacted in 1992 at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. The UNFCCC is the base of all other conventions with international aspects and has currently been ratified by 195 countries and the European Union (http://unfccc.int/kyoto_protocol/items/2830.php, (n.d.), accessed: 23.12.16). The first aim for ratified parties was to stabilise climate forcers within the atmosphere "to mitigate anthropogenic climate change" (Lapveteläinen and Pipatti, 2008). Industrialised countries accepted to sustainably limit emissions, and, as a long-term goal, to stabilise their emissions at the 1990 level by the year 2000 (Lapveteläinen and Pipiatti, 2008). Additionally, the UNFCCC decided to form the United Nations Climate Change Secretariat (UNCCS) as well as to hold follow-up conferences (COP) to enhance the convention (http://unfccc.int/kyoto_protocol/items/2830.php, (n.d.), accessed: 23.12.16). In 1997 COP 3 was held in Kyoto, Japan, to firstly define the precise aims of reducing the climate forcers CO_2, N_2O, CH_4, HFC, PFC, SF_6 in industrialised countries.

The UNFCCC as the major global policy platform (Byrne et al., 2004) thus approved the Kyoto protocol that aims at stabilisation of climate forcers towards a level of climate neutrality, considering anthropogenic interferences on the climate system (Lapveteläinen and Pipiatti, 2008). It is important to note that the Kyoto protocol is the only legally binding mechanism within the UNFCCC (Barthelmes et al., 2015) and it is thus unsurprising that it took until 2005 for the required minimum of 55 parties, who account for at least 55 % of the global emissions, to ratify the protocol. The global context included a separation into industrialised countries ("Annex I") which were required to reduce their emissions by at least 5.2 % compared with the base year 1990 in the first commitment period between 2008 and 2012, and developing countries ("Non-annex I parties"), unpledged to emission reduction (http://unfccc.int/ kyoto_protocol/items/2830.php, (n.d.), accessed: 23.12.16).

Annex I countries were not only committed to individually or jointly reduce emissions to pre-1990 level, but also to publish their yearly emissions as well as to develop and update their mitigation strategy. Furthermore, the Kyoto protocol contains individually quantified emission limitations for Annex I countries and allows emission trading between the parties to successfully reach their targets (http://unfccc.int/kyoto_protocol/mechanisms/ emissions_trading/items/2731.php, (n.d.), accessed: 23.12.16). If a party fails, it is committed to make up the difference plus additional 30 % in the next commitment period (Lapveteläinen and Pipatti, 2008). Even if the UNFCCC and Kyoto protocol are inseparable, they have their differences. They both cover the same gas emissions but differ in reporting them. UNFCCC reports are based on the IPCC 1996 guidelines (Box 5.1) as well as the "Land-use, land-use change and forestry" (LULUCF) procedures (Box 5.2).

IPCC guidelines 1996 and 2006:

- Only anthropogenic emissions are included in the reporting. Emissions and removals from pristine mires are thus excluded.
- The term “managed land” accounts as a proxy to identify human induced emissions (sources) and removals (sinks). Both cases on managed land have to be reported.
- Includes methodological guidance for estimating emissions from energy and agricultural sectors.
- Methane emissions are discussed in the context of degradation / restoration of peatlands, but no methodological guidance is provided.
- Nitrous oxide is the only relevant gas that has to be reported in the agriculture sector.
- CO_2, N_2O, CH_4, NMVOC, Nox and CO emissions have to be reported in the energy sector.
- No methodological guidance is given to estimate emissions from peatland risks such as fires.

In 2006, the guideline was reworked and included further explanations on reporting emissions from peatland soils:

Land use options	GHG	Emissions to be reported under	Recent guidance for managed peatlands (Volume/Chapter)
Tree-covered peatland: - drained afforested peatland	CO_2 N_2O	5.A Forest land on organic soil CRF 5(II) Non-CO_2 emissions	IPCC Guidelines 2006 (4/4) IPCC Guidelines 2006 (4/11)
Tillage farmed peatland: - slightly drained - drained	 CO_2 N_2O	 5.B Cropland on organic soil 4.D Direct emissions, CRF 5(III)	 IPCC Guidelines 2006 (4/4) IPCC Guidelines 2006 (4/11)
Perm. grazed peatland: - slightly or - intensely drained	 CO_2 N_2O	 5.C Grassland on organic soils 4.D Direct emissions	 IPCC Guidelines 2006 (4/4) IPCC Guidelines 2006 (4/11)
Peat extraction emiss. from: - peat extraction fields - decay of horticultural peat - peat combustion	CO_2 N_2O CO_2 All	5.D Wetlands CRF 5(II) Non-CO_2 emissions 5. D Wetlands 1.A CO_2 emissions from fuel combustion activities	IPCC Guidelines 2006 (4/7) IPCC Guidelines 2006 (4/7) IPCC Guidelines 2006 (4/7) IPCC Guidelines 2006 (2/2)

Tab. 5.1: Land-use options for peatlands according to IPCC guidelines and associated categories under which emissions from peatland soils are reported, modified from Barthelmes et al. (2009)

Box 5.1: Summary of the 1996 and 2006 IPCC guidelines with relevance on peatlands, data from Hiraishi et al. (2014), Barthelmes et al. (2009), Lapveteläinen and Pipatti (2008)

However, in the first commitment period the Kyoto protocol reported total emissions based on IPCC 1996 guidelines and considers LULUCF only partially when assessing the fulfilments of the respective parties` commitments. Emissions and removals of climate forcers from forests, croplands or grazing lands had to be chosen by the parties and were treated as voluntary management. If these areas are net sinks, so called “removal units” (RMU), equivalent to one ton of CO_2 were generated to meet the individual targets. If the elected areas were net sources, removal units were added to the difference (Byrne, 2004).

LULUCF – Land-use, Land-use Change and Forestry

The commonly used abbreviation LULUCF stands for “Land-Use, Land-Use Change and Forestry”. The UNFCCC and associated conventions use this compendium as a guidance. Annex I countries have ratified to include LULUCF activities in their climate change mitigation programmes. The relevant carbon pools under the definition of LULUCF are biomass, dead organic matter and soil which can be further subdivided into the following six land-use categories: Forests, Cropland, Grassland, Wetlands, Settlements and Other land. Wetlands are defined as “land that is covered or saturated by water for all or part of the year and does not fall into the forest land, cropland, grassland or settlement categories.” (Lapveteläinen and Pipatti, 2008). As the majority of European peatlands are drained for forestry and agriculture, the LULUCF categories are of utmost importance in the European climate change policies.

Land use options	**GHG**	**Emissions to be reported under**	**Recent guidance for managed peatlands (Volume/Section)**
Tree-covered peatland: - drained afforested peatland	CO_2 N_2O	5.A Forest land on organic soil CRF 5(II) Non-CO_2 emissions	GPG-LULUCF (2003, Sect. 3.2) GPG-LULUCF (2003, App.3a.2)
Tillage farmed peatland: - slightly drained - drained	CO_2 N_2O	5.B Cropland on organic soil 4.D Direct emissions, CRF 5(III)	GPG-LULUCF (2003, Sect. 3.3) GPG-LULUCF (2000, Chap. 4)
Permanently grazed peatland: - slightly or - intensely drained	CO_2 N_2O	5.C Grassland on organic soils 4.D Direct emissions	GPG-LULUCF (2003, Sect. 3.4)
Peat extraction emissions from: - peat extraction fields	CO_2 N_2O	5.D Wetlands CRF 5(II) Non-CO_2 emissions	GPG-LULUCF (2003, App.3a.3) GPG-LULUCF (2003, App.3a.3)

Tab. 5.2: Land-use options for peatlands according to LULUCF and associated categories under which emissions from peatland soils are reported, modified from Barthelmes et al. (2009)

Box 5.2: LULUCF introduction, data from Hiraishi et al. (2014), Barthelmes et al. (2009), Lapveteläinen and Pipatti (2008)

According to the UNFCC definition, peatlands were not a land use category such as cropland, etc. but merely a type of soil substrate with a land use option upon it (Barthelmes et al., 2009). Therefore the Kyoto protocol did not account for carbon loss by drainage and de-vegetation of peatlands (Byrne, 2004) and thus provided no incentives for peatland rewetting in the first commitment period (Barthelmes et al., 2015). The voluntary option of land use management included accounting for all the relevant gas fluxes from all countrywide land areas subject to that.

Activity	Practice
Deforestation*	•Felling and draining of a forest on organic soil and subsequent conversion to cropland or grassland. •Rewetting of forest that raises the water table to such an extent that the forest cannot persist or regenerate. •Rewetting and felling of forests, e.g. to restore a non-forested peatland.
Afforestation/Reforestation*	•Drainage of a (non-forested) peatland for forestry, e.g. when a treeless or sparsely forested peatland is drained to stimulate tree growth. •Rewetting of a (non-forested) peatland for forestry, e.g. when grassland on organic soil is rewetted and afforested with Alder trees.
Forest Management*	•Drainage of forest on organic soil that remains a forest, e.g. when a forested peatland is drained to stimulate tree growth. •Rewetting of forest on organic soil that remains a forest, e.g. when an Ash forest on organic soil is rewetted and replaced by an Alder forest.
Cropland Management**	•Drainage of a (non-forested) peatland and conversion to cropland. •Rewetting of a cropland on organic soil that remains a cropland, e.g. when a potato field on organic soil is rewetted for paludiculture.
Grazing Land Management**	•Drainage of a (non-forested) peatland to improve grazing. •Rewetting of grassland on organic soil that remains grassland, e.g. when a drained grassland used for dairy cow husbandry is rewetted to a grassland for water buffalo husbandry.
Re-vegetation**	•Re-vegetation and rewetting of a (non-forested) peatland, e.g. when a bare peat extraction site is converted to a vegetated wetland.
Wetland Drainage and Rewetting (if elected)**	•Rewetting or draining (after 1990) of a (non-forested) peatland that is not yet accounted for under any other mandatory or elected activity.

*Tab. 5.1: Overview of LULUCF activities under the Kyoto Protocol with examples of the practices of 'drainage' and 'rewetting' that must be reported under the respective activity. * = mandatory accounting; ** = mandatory accounting if elected by the party for the first reporting period (taken from Joosten et al., 2015)*

Barthelmes et al., (2015) elucidate that that if one of the Annex I parties wanted to claim emission reductions from e.g. 100 km^2 rewetted grassland on peat, it also had to account for the emissions of the remaining e.g. 10 000 km^2 drained grasslands on peat and additionally for emissions of all grasslands on mineral soil. Consequently, it is not surprising that few of the parties that ratified the protocol chose the cropland or grassland management options, and instead preferred forest management due to practicable monitoring procedures (Ellison et al. 2011). Peatland related emission targets were later considered. At the COP 17 meeting in Durban, 2012 the terms "wetland drainage" and "re-wetting" were adopted by the UNFCCC under article 3.4 of the Kyoto protocol, giving the opportunity for Annex I parties to account for human induced gas fluxes from organic soils (peatlands) in the second commitment period (2012 – 2020) as well as to choose the "Peatland rewetting and conservation" (PRC) option of the Verified Carbon Standard (VCS) to generate and trade carbon credits from peatlands on the voluntary carbon market (see chapter 5.4) (Barthelmes et al., 2015). However, the term "wetland drainage" has been regarded as being a misleading definition, as the definition refers only to peatlands (organic soils) and disregards other types of wetlands (Barthelmes et al., 2015).

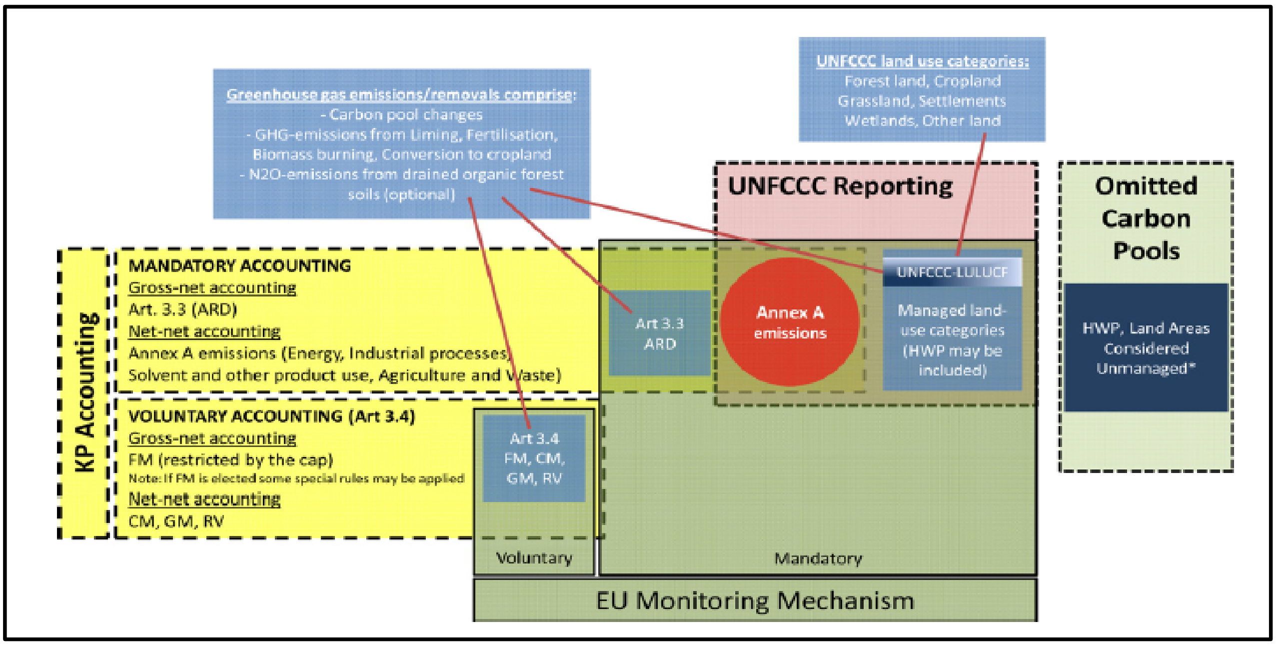

Fig. 5.1: Overview about carbon accounting and reporting frameworks (image taken from Ellison et al., 2011)

At COP21 held in Paris 2015, the so called "Paris Agreement" was enacted. It builds on the convention and the Kyoto protocol but focuses on joint climate change mitigation and adaption on the international level. The additional aim is to limit climate warming to 1.5 degrees about pre-industrial level. In article 5 of the agreement, it is stated that the UNFCCC encourages ratified parties to "conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1(d) of the Convention, including forests" (http://unfccc.int/paris_agreement/items/9485.php, accessed: 25.12.2016). This was an important breakthrough on the international political level for the restoration of peatlands. The importance of "reducing GHG emissions by securing, restoring and rewetting peatland areas" (http://www.fao.org/climate-change/international-fora/major-events/unfccc-cop-21/en/, accessed: 25.12.2016) was introduced and developed at UNFCCC COP 22 in Marrakesh, which was also a conference of the parties of the Kyoto protocol as well as Paris agreement (http://unfccc.int/meet-

ings/marrakech_nov_2016/meeting/9567.php,accessed 25.12.2016). Peatlands and the importance of their restoration as a strong option for climate change mitigation finally came to the fore. The Global Peatlands Initiative was launched to “save peatlands as the world’s largest terrestrial organic carbon stock and to prevent it being emitted into the atmosphere” at a global or national level (www.globalpeatlands.org).
Even if it is obvious that a new era for the restoration of peatlands in the context of an internationally political framework has begun, neither the UNFCCC nor the Kyoto protocol introduce ways of reducing emissions. The question of “how” has to be addressed by debates at the EU and national levels (Ellison et al., 2011), but many ways have been proposed by several European and national climate initiatives for peatlands emissions. The following framework conventions of the importance on climate change mitigation through restoration of peatlands as well as peatland conservation shall briefly be discussed. Additional information can be found on the weblinks provided.

Ramsar Convention on Wetlands (www.ramsar.org)

The Ramsar convention on wetlands is the oldest intergovernmental organisation, dealing with conservation and sustainability of natural resources. It builds the framework for international and national action on conserving wetlands. Besides establishing management plans, monitoring, supervision and close collaboration with other policies and conventions, the Ramsar convention legally binds its member countries to public relations and the inclusion of wetland domestic population. Each member country needs to designate at least one wetland meeting the criteria for the list of wetlands “of international importance” including to account for conservation of the wetlands ecological character. Currently 169 countries with a total of 2241 wetlands of international importance are listed as members. As these cover all types of wetlands, peatlands are underrepresented but protection, conservation and especially the obligatory public relations procedures are highly beneficial to climate change mitigation in context with peatlands.

Additional recent information can be found in: Ramsar Convention Secretariat, 2016, *Fourth Ramsar Strategic Plan 2016 – 2024. Ramsar handbooks for the wise use of wetlands*, 5th ed., Vol. 2, Gland, Switzerland

Wetlands International (www.wetlands.org)

Wetlands International present themselves as the only global non-profit organisation campaigning for wetland conservation and restoration. With experts in all related fields, Wetlands International has a high quality reputation. The organisation has strongly influenced UNFCCC policies including the Kyoto protocol and the Paris Climate Agreement. It has further provided incentives to reduce carbon emissions from degrading peatlands and aims at the restoration of natural long-term carbon sinks. Wetlands International helps to establish scientific frameworks on emissions of climate forcers from peatland degradation and related risks.

Food and Agriculture Organisation of the United Nations (FAO, www.fao.org)

The FAO has started to pay attention to peatlands and organic soils in climate debates. In the framework of the MICCA (Mitigation of Climate Change in Agriculture) programme it points to the emissions and land subsidence due to peatland drainage driven by forestry and agriculture and aims at supporting countries that have ratified conventions within the

UNFCCC. Furthermore, monitoring and assessing gas fluxes as well as assessment of mitigation potentials in agriculture are key aspects of the MICCA programme. The report "Peatlands – guidance for climate change mitigation through conservation, rehabilitation and sustainable use" and further information about the programme can be found at http://www.fao.org/in-action/micca/knowledge/peatlands-and-organic-soils/en/

UNESCO World Heritage Convention (www.en.unesco.org)

The UNESCO not only aims at preserving cultural properties but also accepts the importance of nature conservation and the balance between mankind and their interaction with nature as their habitat. Peatlands came to the fore in the European Archaeological Council which stated the importance of wetlands "for the preservation of cultural features". Wetland biodiversity was connected within the document "Strategy for the Heritage Management of Wetlands" in 2001. Since then, many peatlands – global and European – have been inscribed properties of the World Heritage List or are currently on the tentative list. The nomination of a peatland for the World Heritage List offers not only a preserved status but also financing options and enormous public relation possibilities. More about wetlands and cultural heritage conservation can be found at:
http://www.ramsar.org/news/wetlands-and-cultural-heritage-conservation-0

International Mire Conservation Group (IMCG, www.imcg.net)

The IMCG is an international network of peatland specialists, promoting conservation of mires and related ecosystems as well as information exchange about related topics. It publishes the scientific journal "Mires and Peat" jointly with IPS , as well as newsletters edited by leading peatland biodiversity specialists. Some of the most important projects include the Global Peatland Database (in progress) and the IMCG European Mires Project. The IMCG also provided manuals and guidelines for peatland restoration and wise use strategies.

International Peat Society (IPS, www.peatsociety.org)

The international Peat Society describes itself as a "non-governmental, non-profit multidisciplinary organisation dealing with peatlands and peat". Its focus is on economic, social and environmental values of peatland resources as the organisation is linked to the peat industry. Members are not only peatland specialists, but also industrial and regulatory stakeholders. The collaboration of scientists and stakeholders to find a balance between ecological and economic needs is progressive and promising for other branches such as the agricultural sector.

5.2) European framework conventions on climate change

European peatland conservation programmes and procedures are defined by formalities and global climate conventions. Generally, the status of peatlands within Europe and the EU is insufficient due to the difficult task to balance the agricultural sector and climate commitments. Most climate related restrictions are issued by the UNFCCC but EU regulations differ somewhat and it is necessary to understand them in order to understand the situation at the national and community level.

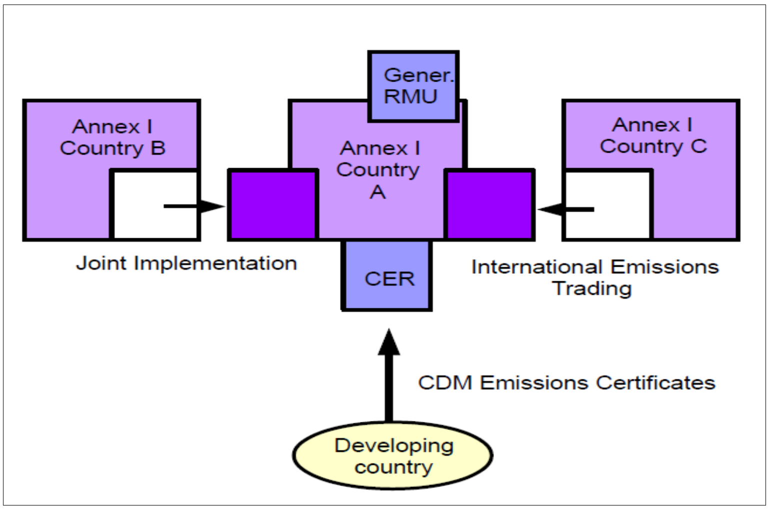

Fig. 5.2: Emission trading under the Kyoto protocol (modified from BMUM, 2015)

European Climate Change Programme (ECCP)

Under pressure by the Kyoto protocol, the EU was required to reduce emissions to 8% below pre-1990 level in the first commitment period 2008-2012 (https://ec.europa.eu/clima/policies/eccp/first_en, accessed: 25.12.2016). Considering that the EU is with 173 Mton CO_2 equivalents per year the second largest emitter from drained peatland (Joosten et al., 2011), it was assumed that special regulations on peatlands would be proposed by the convention. As a response, the European Climate Change Programme was launched, which aimed to identify and develop necessary elements for implementing the Kyoto protocol (https://ec.europa.eu/clima/policies/ eccp/first_en, accessed: 25.12.2016). In the ECCP, the Commission, stakeholders, non-governmental organisations as well as scientists worked together. In the first period, there have been three groups related to emissions from peatland addressing the fields of agriculture, sinks in agricultural soils and forest related sinks to find other whether electing cropland or grassland under LULUCF is reasonably practical or not (Weiske, 2007). The potential of gas emission reduction by storing carbon has been stated as a possible option by the sinks in agricultural soils group (Weiske, 2007). Additionally, a permanently shallow water table on peatlands is the most promising procedure for carbon sequestration (ECCP, 2001). Later, in the second commitment period of the Kyoto protocol and the introduction of the new LULUCF activity “Wetland Drainage”, the EU aligned based on preceding scenarios for potential carbon sequestration in European agriculture additional LULUCF accounting rules. It has furthermore been stated that accounting for emissions from cropland management and grazing land management are mandatory from 2021 onwards (Barthelmes et al., 2015). As most drained European peatlands were drained for agriculture, rewetting or peat mining lifting of the water table is a promising option in the near future to prevent anthropogenic climate warming and to conserve peatlands in Europe (Joosten and Clarke, 2002; Barthelmes et al, 2015).

EU Common Agricultural Policy (CAP)

The Common Agricultural Policy (CAP) is the oldest European policy framework on agriculture. It includes payments of subsidies on which agricultural businesses are built and thus define how and when land is used and managed. The CAP thus provides a powerful instrument of regimentation if reasonably utilised. Cross-compliance (CC) regulations also include habitat care but are often disregarded by farmers (https://ec.europa.eu/agriculture/ cap-overview_en, accessed: 25.12.2016). Unfortunately drained peat is omitted from the CC-rules for soil organic matter and intense farming on peat soils still receives EU subsidies (Barthelmes et al., 2015).

EU Emission Trading System (ETS)

The Emission Trading System under the EU differs from that in the Kyoto protocol. In the first trading period, only CO_2 emissions from power generators and energy-intensive industries were covered. In the second period N_2O emissions were included by a number of countries. Biomass is considered to be CO_2 neutral and biomass fuels including peat have an emission factor of zero (http://ec.europa.eu/clima/policies/ets/pre2013_en). The ETS covers thus only two of all 6 Kyoto protocol gases.

EU Natura 2000

The aim of the EU Natura 2000 network is to secure the “long-term survival of Europe's most valuable and threatened species and habitats” (http://ec.europa.eu/environment/ nature/natura2000/index_en.htm, accessed: 25.12.2016). Čivić and Jones-Walters (2010) describe it as “the most important and influential ecological framework in Europe”. The Natura 2000 habitat annex I directive includes under point 7 several peatland types and lists around 10000 sites. The quick facts are provided in the list for each habitat types, including the conservation status subdivided into areas. This habitat list can be found on http://eunis.eea.europa.eu/habitats.jsp and is an important tool to get an overview about the amount and status of European peatlands.

EU Water Framework Directive (WFD)

The WFD aims at increasing “the resilience to climate change of health, property and the productive functions of land, inter alia by improving the management of water resources and ecosystems" (http://ec.europa.eu/environment/water/adaptation/index_en.htm, accessed: 25.12.2016). The directive covers surface and ground waters and is strongly connected to “waterdependent” Natura 2000 sites (Barthelmes et al., 2015). It includes peatlands which are therewith by law protected against further degradation. Unfortunately, reality reveals a different picture. Water protection procedures must be taken seriously and significant support to reduce water pollution due to fertilizers should be one important step to preserve or restore nutrient sink functions of European peatlands if degradation has not proceeded too far.

5.3) European and national climate initiatives for peatland emissions

There are numerous national climate initiatives focussing on peatland restoration and conservation in Europe. Most countries provide at least one initiative or research institute and most of them are interconnected sharing results or helpful information relating to peatlands as net sinks or sources for climate relevant gas emissions. It would go beyond the scope of this chapter to introduce all of them, the some of the most influential in an international context shall be introduced here.

Nordic Baltic Wetlands Initiative (NorBalWet, www.norbalwet.org)

The Nordic Baltic Wetlands Initiative (NorBalWet) is based on the Ramsar resolution 8.30 as a "regional initiative for further implementation of the convention" (www.norbalwet.org, accessed: 24.12.2016) and aims at the conservation and wise use of wetlands. The idea behind it is to strengthen the countries which contain the majority of Europe's peatlands in one interacting network. It is today recognised as a Ramsar regional initiative and includes the following participating countries: Denmark, Greenland, Faroe Islands, Estonia, Finland, Iceland, Latvia, Lithuania, Norway, Sweden as well as the European oblasts of the Russian federation. NorBalWet includes several strategies on country individual level to successfully protect and manage wetlands around the Baltic Sea. This kind of communicating network is unique in Europe and even welcomes individual stakeholders, communities or non-governmental organisations.

Irish Peatland Conservation Council (IPCC, http://www.ipcc.ie/)

With the largest area of bogs in Europe and extensive experience within the peat industry, the Irish Peatland Conservation Council (IPCC) develops and publishes action plans on national strategies for conservation and management of all peatland types in Ireland. As every peatland of importance for conservation is affected by peat extraction (Malone and O'Connell, 2009), plus degradation and burning are common circumstances for providing grasslands, the IPCC meets a challenge in communicating national climate related conventions on peatlands. The IPCC is notable compared to other national peatland initiatives, as it not only addresses stakeholders and communal politicians but directly wants to affect interested local community members.

Michael Succow Foundation, Germany (http://www.succow-stiftung.de/home.html)

Contrary to the Irish Peatland Conservation Council, the Michael Succow Foundation's goal is to inform decision makers, UNFCCC delegations and IPCC scientists about peatland and climate protection. The foundation was founded by Dr. Michael Succow and operates at a national and international level. The international focus lies on the development of peatland related aspects and the formation of nature conservation areas in Azerbaijan, Turkmenistan, Uzbekistan, Russia and Belarus. The foundation takes a holistic approach to conservation and addresses all aspects occurring in peatland habitats. Their projects and publications are held in high regard and the Michael Succow Foundation is known to support all relevant international framework conventions and initiatives with its knowledge.

Finnish Peatland Society (http://www.suoseura.fi/eng/index.html)

The Finnish Peatland Society is the oldest research based scientific society, aiming at research and promotion of peat and peatland related topics. It publishes books about peatlands as well as the international trade journal “Suo – Mires and Peat”.

Clima East (http://www.climaeast.eu/)

Clima East is a project funded by the European Union with the aim to assist participating countries (Armenia, Azerbaijan, Belarus, Georgia, Moldova, Russia, Ukraine) in the current challenge of climate change mitigation and adaption. It not only focuses on the development of plans and strategies with theoretical support, but also includes pilot projects to develop sustainable approaches to climate change. Some examples include the conservation and sustainable management of peatlands in Belarus, the Ukraine and Russia as well as restoration and protection of forests and peatland permafrosts in Russia.

German Peat Society (DGMT, http://www.dgmtev.de/index_englisch.html)

The German Peat Society is, like the Finnish Peatland Society, a research based scientific society with the mission to enhance peatland research in all relevant areas. It has due to its members an international character and publishes the well-known journal “TELMA”.

5.4) Compliance and voluntary carbon markets

There are two categories of emission trading and carbon markets: Voluntary carbon offset markets, and compliance carbon markets, which allow actors to offset against national or international mandatory regulations (Joosten et al., 2015). Under international climate regulation schemes, there are flexible mechanisms for Annex I countries to trade emissions, usually in the form of carbon credits which are traded or “sold” in metric tons of CO_2 or CO_2 equivalents (t CO_2 eq). This gives ratified countries the possibility to reduce emissions where reduction procedures are cheapest and easiest to achieve (BMUM, 2015). Trading saved emission surpluses might lead to accelerating incentives for Annex I countries.

Under the Kyoto protocol, participating countries have the following options for trading carbon credits in the compliance carbon market (according to Joosten et al., 2015):

- Clean Development Mechanism (CDM) emission certificates (Certified Emission Reductions, CER) are achieved by financing climate protection projects with a function of net-sinks in so called developing countries
- Joint implementation (JI) emission certificates (Emission Reduction Units, ERU) are achieved by financing climate protection projects with a function of net-sinks in non-Annex I countries
- Trading saved emission surpluses (International Emissions Trading, IET) to other Annex I countries that are not willing or capable to meet the convention
- Receiving certificates for carbon sinks (Removal Units, RMU) by offsetting national “net carbon sink activities” (according to article 3.3 and 3.4 of the Kyoto protocol)

O'Sullivan et al. (2012) stated that the voluntary carbon market is currently the only option that gives the possibility to finance peatland projects. In 2010 the Verified Carbon Standard (VCS, www.v-c-s.org) developed its own programme for peatland restoration and introduced the category “Peatland rewetting and Conservation” (O'Sullivan et al., 2012). Since then, there have been an increasing number of projects that offer carbon credits by carbon sequestration in peatlands to private persons and companies which aim to reduce their carbon footprints. As ecological restoration projects are particularly attractive for the companies' public relations, there are reasonable concerns regarding sustainable development (O'Sullivan et al., 2012). Buying carbon credits to achieve CO_2 neutrality might weaken the responsibility to tackle the underlying problems in matters of sustainable climate development (Dunn and Freeman, 2011). Effective peatland projects must meet specific quality criteria and include long-term values. Usually, projects get verified by using a third party’s standard as the VCS or Gold Standard. The verification of “sold” goals have to be evaluated by emission reduction assessments.

How carbon offsetting in the private sector works can be seen in the following illustration:

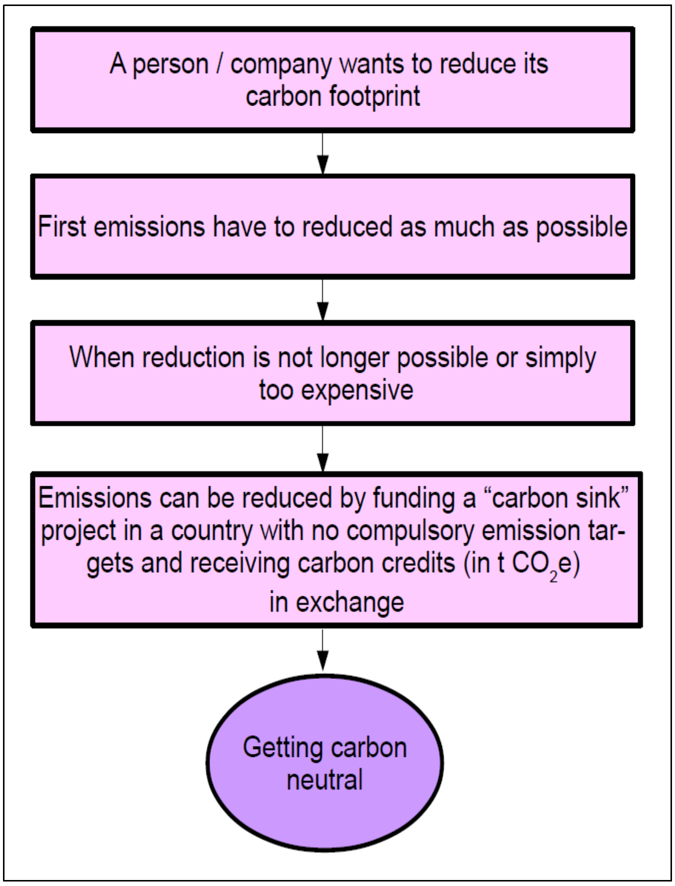

Fig. 5.3: How does voluntary carbon offsetting work? (own illustration)

Compliance and voluntary carbon markets offer great opportunities for peatland restoration projects but the regulations have to be refined. There are still barriers that complicate accreditation before accessing carbon markets. Especially for accessing markets under the Kyoto protocol, a change in law would be required (Reed et al., 2013) and not a deportation into agricultural responsibilities.

6) Strategies of peatland management

Fig. 6.1: Restored peatland: Haapasuo Bog in Leivonmäki National Park in central Finland, photo taken from Ecological restoration in drained peatlands, Similä et al. (2014)

6.1) Why restore peatlands?

As already shown in the previous chapters, the importance of peatlands in the climate debate plays a major role and the potential of carbon sequestration due to restoration or conservation of anthropogenic degraded peatlands cannot be dismissed. The northern peatlands only account for approximately one third of the total global carbon storage but on the other hand also for about 20 – 30% of all global methane emissions (Tuittila and Laine, in Similä et al., 2014). As European peatlands, especially in northern countries, are often large, they affect large communities (Cris et al., 2014) but also have been damaged due to commercial use such as peat mining and agriculture (Similä et al., 2014). Actively degraded peatlands clearly lost their function as carbon sinks and have seen a decline in fauna and flora, but it has also been reported that due to neighbouring forestry and agriculture even many undrained peatlands are no longer in their natural state (Similä et al., 2014). The overall goal to restore these functions is thus the restoration of suitable peatlands to recover natural conditions in anthropogenic affected areas (Beyer and Höper, 2015; Similä et al., 2014). In sites where degradation has proceeded so far that neither the hydrologic base nor a minimum peat layer is available, restoration procedures would be incommensurate and in most cases useless. Gas flux measurements from different monitored sites have shown that within approximately 30 years, restored peatlands become carbon sinks if inundation is avoided and natural conditions established (Beyer and Höper, 2015). During the first years after rewetting, peatlands might act as sources of climate forcers with global warming potential rates of 760 to 2253 CO_2 eq m^2 / yr (Harpenslager et al., 2015) due to high rates of methane emissions. These methane spikes are assumed to show up in the first 10 years after rewetting with rates of approximately 2.5 t CO_2 eq ha / yr (Moxey and Moran, 2014) – therewith offsetting carbon storage in the short-term. In the long-term, the methane cycle recovers after raising the water table slowly but continuously as microbes (a key factor for the cycle) recover (Tuittila and Laine, in Similä et al., 2014). After the re-establishment of these natural chemical conditions, restored peatlands act as long term sinks (Beyer and Höper, 2015) or emissions are at least reduced compared with pre-restoration values. Concrete examples from different sites in Europe show carbon sequestration rates ranging from 1.08 t CO_2 ha / yr in Finland (Tuittila and Laine, in Similä et al., 2014) to 2.9t CO_2 ha / yr in Belarus (Anzaldua and Gerdes, 2011) over the first ten years after rewetting. Studies from Scotland have shown that sequestration rates increase by time due to "maturing" conditions (Artz and Donnelly, 2012).

It is thus the task of a proper strategic management plan to asses which sites are suitable to restore for the purpose of climate change mitigation. Taking action is important, as studies have shown that self-regulatory functions of peatlands after mining or intense agricultural use are very low (Similä et al., 2014). Canadian bare peatlands only spontaneously recolonised on 17% of the total area (Quinty and Rochefort, 2003). This thesis will now introduce the main steps for successful peatland restoration, highlight problems and techniques and evaluate generalised costs for basic procedures as well as possible land use options for restored peatlands. The interested reader might find additional information in relevant guidelines and handbooks such as:

- Ecological restoration in drained peatlands (Similä et al., 2014)
- Global peatland restoration manual (Schumann and Joosten, 2008)
- Conserving bogs – the management handbook (Brooks et al., 2014)
- Peatland restoration - an introduction, (IUCN UK Peatland Programme, 2009)
- Global peatland restoration demonstrating success, (Cris et al., 2014)
- Peatland restoration guide, 2.ed.(Quinty and Rochefort, 2003)

6.2) Strategic management planning

Peatlands are complex systems and require a comprehensive approach when planning restoration or conservation. It is essential to understand the basic principles of peatlands and peat formation, as human induced impacts such as drainage as well as the theoretical results of peatland restoration and many other differed aspects have to be considered. For this purpose, every restoration project requires a preliminary assessment and a project plan including detailed definitions of goals and objectives. There are three main goals when reading relevant literature about peatland restoration:

- Promotion of biodiversity
- Climate change mitigation
- Ecosystem regulation

The objectives are well defined aims that must be executed to meet the goal. These are by definition linked to certain activities (Quinty and Rochefort, 2003). The primary goal is usually to re-establish natural conditions for the promotion of a self-regulating peat accumulating ecosystem. This long-term goal is accompanied by objectives that are commonly accepted: Raising the water table and restoration of specific peat vegetation. This also includes limiting further degradation and stopping a decline in ecosystem diversity (Similä et al., 2014; Schumann and Joosten, 2008). According to Schumann and Joosten (2008) not all features can be restored at once and necessarily need to be restored, it is important to assign priorities by asking three important questions:

- What do you want to restore?
- Is it possible?
- What do you have to do to reach the goal?

To answer this, it is indispensable to describe the present state of the site and to identify problems and particular key processes (Rehell et al., in Similä et al., 2014). The need for measures and their practical handling should be defined in detail and in advance, as the feasibility of realisation is highly depending on measures. It is advised to refer to historical records or photographs of the sites (Similä et al., 2014) or to use a reference ecosystem as a “model” (Quinty and Rochefort, 2003) when planning a project. The size of the restoration area is also of particular importance and should be assessed carefully. It is more beneficial and cheaper to restore a large area at once than several smaller ones, but this is not always possible and realistic due to ownership or surrounding land-use. In these cases, partial restoration and its possible benefits should be considered (Rehell et al., in Similä et al., 2014).

In summary, it is essential to define the following aspects when outlining a project plan:

Historical site characteristics	- By historical photographs or records
Hydrology	- Peatland is defined by its hydrology - Goals typically include raising of the water table and establishing natural water flows - Assesses the whole catchment area, eventually using photographs / a helicopter - Determines options between restoration and reclamation - Determines restoration techniques
Topography	- Determines restoration techniques and possibilities - Indicates possible problems - Include surrounding landscape into assessment
Peat characteristics / Chemistry	- Peat thickness, type, decomposition, chemistry is essential to choose management options - Chemistry determines right water conditions for peatland plant species to thrive
Vegetation and species	- Development of peat forming vegetation is a prerequisite for peat formation (→ especially Sphagnum mosses) - Current species and the expected impact after restoration should be evaluated - Existing vegetation gives clues on current chemistry and -water conditions
→ Goals	- Should be defined now
→ Objectives	- Should be defined now including further land use
Measures and techniques	- Appropriate measures and neatly defined restoration techniques are essential for success

Sources of material	- Planning materials in advance lowers costs and saves time - Plant transplantation sources need to be defined
Monetary assessment and financial resources	- Plan monetisation after rewetting and ensure integration of criteria for climate forcers are integrated in credible certification schemes - Apply for financial resources and carbon markets
Monitoring	- Essential after restoration procedure - Includes climate forcers, biodiversity, hydrology - Improves measures and planning for future projects - Necessary to evaluate progress, effectivity, efficiency - Identifies problems - Determines success of objectives and the project - Must be done regularly from the second year on

Tab. 6.1: Necessary information to consider when planning a restoration project. Own work, based on Similä et al. (2014), Quinty and Rochefort (2003), Moxey and Moran (2014), Schumann and Joosten (2008), Cris et al. (2014), Schäfer (2010).

A final management plan should be based on these considerations and include detailed information specific to the audience (e.g. politicians, community, scientists, etc.).
Brooks et al., (2014) give detailed examples in their book “Conserving bogs” and Schumann and Joosten published a “Checklist for restoration projects” in 2008 which can help determine objectives to focus on for an effective and efficient restoration plan.

6.3) Restoration techniques

Fig. 6.2: a) A completed plastic piling dam b) Small peat dams c) A completed and working timber dam d) Re-profiling, a)-c) taken from Brooks et al., Conserving Bogs (2014); d) taken from IUCN UK Peatland Programme, Peatland Restoration - An introduction, (2009)

Blocking and Damming

When outlining the project plan, it is obligatory to consider the right restoration techniques for the relative peatland sites. These vary widely in type and procedure and it might be challenging to choose the appropriate techniques. In the following, some of the basic approaches of restoration measures are introduced.

Blocking and damming grips, gullies and channels is the essential basis to restore hydrological conditions including elevation of the water table and therewith providing anaerobic conditions which on the long-term lead to active peat formation (Brooks et al., 2014). These procedures reduce or event prevent erosion as the water flow slows down and sediment gets trapped. There are numerous techniques to block or dam with peat, wooden dams, stone or plastic dams depending on depth and with of the ditches (See fig. 6.1 for damming guidelines). Sometimes the use of geotextiles is recommended (Vesterinen et al., in Similä et al., 2014). The main aspect in constructing dams is that they must be large and stable enough to withstand strong water pressure (Brooks et al., 2014).

Width	Depth	Material
< 1m	< 1m	Peat (by hand) Polyethylene sheet and peat Ply sheet Corrugated steel
< 2m	1m	Peat (by machine) Ply sheet Plastic sheet (unsupported) Plastic piling
> 2m	1m	Peat (by machine) Plastic sheet (supported) Solid plank Composite Plastic piling
> 3m	> 1.5m	Peat (by machine) Plastic piling Composite

Tab. 6.2: Damming guidelines, taken from Brooks et al. (2014)

Measures for trees

Clearance of trees including their stumps might be necessary in peatlands which in their natural condition are characterised by minor tree populations. Removal of trees leads to reduced evapotranspiration, which activates peat formation (Schumann and Joosten, 2008). It also increases natural light conditions (Vesterinen et al., in Similä et al., 2014) and leads to reduced aerobic conditions by removing deep rooting vegetation (Schumann and Joosten, 2008). In some areas, depending on chemical conditions, tree material should be removed to reduce noxious substances (Schumann and Joosten, 2008). It is important to consider the right time for tree clearance. When using heavy machines, it might be easier to wait until the ground is frozen in winter, or to harvest during summer, when the water table is generally lower. When only a few trees are present, it should be considered whether harvesting is reasonable or not – most trees die in any case when the water level is elevated (Vesterinen et al., in Similä et al., 2014).

Bare peat recovery / Vegetation

Peat exposure favours erosion and decomposition by aerobic microbes. Thus one of the major objectives within peatland restoration is to re-establish peatland specific vegetation on bare peat, which is mostly caused by overgrazing, vehicle damage, peat extraction or fires. Re-establishment by plant transplantation is one successful method e.g. spreading heather brash which is rich in peatland specific mosses (IUCN UK Peatland Programme, 2009). Another option is to spread peat including seeds, together with carefully applied fertilisation (Quinty and Rochefort,2003). In both cases, transplantation might be cost- and time-intensive and it is sometimes challenging to find the right donor sites (IUCN UK Peatland Programme, 2009). However, all methods lead to increasing stabilisation and active peat formation if habitat conditions are suitable.

Other problems

Generally, special attention should be directed to safety issues. It can be dangerous to use heavy machines on soft ground (due to subsidence) so experienced drivers are beneficial. The risk of peat fires has to be considered when working during the summer months and a fire risk plan should be available (Joosten et al., 2015). Site specific problems might occur on sloping sites, as these usually carry large amounts of water that might be difficult to dam (Vesterinen et al., in Similä et al., 2014). Nutrient rich peatlands are also challenging due to specific chemical conditions. In these places, it is necessary to channel the water to the right places for success (Vesterinen et al., in Similä et al., 2014).

6.4) Average costs for restoration projects and possible funding options

Costs and funding opportunities are complex and vary strongly between European countries. This subject can thus only be briefly introduced, as it would go far beyond the scope of this thesis to work out general costs for the different European regions. Generally, restoration costs are dependent on the site area, the type of peatland and the prevenient impact. Time and working hours is an important factor in every cost calculation. Restoration projects regardless of cost-benefit calculations are not rational and receive only low recognition. The main factor to finance peatland restoration can be found in administration and management costs as well as executive staff salaries and social payments. Therefore these must be taken into account, in addition to the costs for restoration procedures (machines and material). By using local materials and limited activities, costs can be reduced. Given that average restoration costs for all European countries can be found in the range of 2135 to 7335 € per hectare, the resulting mean value is approximately 4735€ (table 6.3). Benefits of avoided emissions in t CO_2 eq range from 30 – 50€ (Joosten et al., 2015) and the resulting avoided CO_2 costs are assumed to equal 728€ ha^{-1} yr^{-1} at average carbon sequestration rates of 0,15 – 1,5 t CO_2 ha^{-1} yr^{-1} in Europe's boreal and temperate regions (Joosten and Clarke, 2002; Höper, 2007, Tolonen and Turunen, 1996).

Country	Cost ranges in € per hectare	Source
Germany	3000 – 5000 (incl. land purchase)	Förster and Schäfer (2009)
Poland	800 – 3100 (incl. topsoil removal)	Klimkowska et al. (2010)
The Netherlands	10000 – 30000 (incl. topsoil removal)	Klimkowska et al. (2010)
Belarus	15 - 150	Anzaldura and Gerdes (2011)
Ireland	400	Bord na Mona (2015)
Great Britain	235 - 11700	Moxey and Moran (2014)
Finland	500 - 1000	Virnes (2013)
Total average:	**2135 - 7335**	

Tab. 6.3: Overview about European restoration costs in Euro per hectare

As a result, expenses are recouped within the first seven to ten years with constant emission rates. This is followed by a period of economic benefits. On long-term rates, the benefits of peatland restoration and conservation rise with every decade to an assumed value of around 1150€ per hectare in 2080 (Graves and Morris, 2013). Monetising the rewetting and subsequently offering credits on the carbon market is one of the key factors to make rewetting of peatlands a successful enterprise.

Measures	Cost range
Mechanised harvesting of saleable timber from a peatland (incl. felling and forest haulage to roadside)[a]	€ 11 – 20/ m^3, average € 14.23/m^3
Long-distance transportation of saleable timber to a mill[a]	€ 6 – 10/ m^3, average € 8.16/m^3
Energy wood harvesting (incl. forest haulage to road-side)[a]	€ 20 – 35/ m^3 s.u.b.
Manual tree-felling (4-11m^3/day)[b]	€ 25 – 63/ m^3
Forest haulage to roadside of trees felled by foresters[b]	€ 4 – 14/ m^3
Clearing of ditch lines by foresters (trees left in site)[b]	€ 0.5 – 1.5/ m
Continuous infilling of ditches, pine bogs and other larger peatland sites[c]	€ 0.45 – 1.2/ m
Continuous infilling of ditches, sites with several smaller spruce mires[c]	€ 0.75 – 2.5/ m
Dams made of peat[d]	€ 15 – 25/ dam
Dams reinforced with wood and geotextile (incl. Materials and costs of forestry assistants 40 €/h)[d]	€ 80 – 140/ dam
a) 2010 and 2011, not incl. value added tax b) 2007 – 2008, 3 sites in an area run by Natural Heritage Services, S. Finland, in Saimaa c) 2005 – 2009, 8 sites in an area run by Natural Heritage Services, S. Finland, in Saimaa d) 2008 – 2009, 8 sites in an area run by Natural Heritage Services, S. Finland, in Saimaa	

Tab. 6.4: Costs of various peatland restoration measures, modified from Similä et al. (2014)

Similä et al. (2014) presented average costs for restoration procedures for Finland which gives an insight into an average range for Europe (table 6.4). Procedures in central and eastern Europe are assumed to be cheaper, while more expensive on the British Isles (table 6.3).

Funding options

Private funding in the context of the development of voluntary carbon markets is an increasing opportunity for restoring peatlands in matters of climate mitigation (Cris et al., 2014). Funding of projects under EU programmes, especially under EU Life and Natura2000, has so far assisted over 260 peatland restoration projects and continues to support ongoing projects (Cris et al., 2014).

6.5) Land use options of restored peatlands

Farming

Paludiculture is the new term propagated for post-restorage land use. On bogs sphagnum farming is most common, whereas fens may serve for canary grass, reed, sedges or alder farming (Wichtmann, 2016; Joosten, 2009). This aims at providing an alternative for biomass production on arable peatland and reduction of fossil fuels.

Sphagnum farming is a growing sector, has a neutral climate impact and provides a successful alternative for peat used in horticulture (Beyer and Höper, 2015). Farming of grasses and trees is a relatively new land-use option, as larger areas and special machines are necessary. Good examples can be found in central and eastern Europe where reed still is an important building material. Comparison of the productivity with emissions shows clearly that peatland specific grasses are a good and climate friendly alternative.

Peatland use	Productivity in t dry mass ha/yr	Emissions in t CO_2 eq ha/yr
Drained for agriculture	8 - 25	> 20 - 60
Canary grass	3.5 - 15	12
Reed	3 - > 25	10
Sedges	3 - 12	0 - 8
Alder	3 - 10	0

Tab. 6.5: Productivity of crop alternatives on peatlands, from Wichtmann (2016)

For successful farming under EU policies and subsidies in agriculture, adjustments of current frameworks are required to give farmers incentives to switch to alternative land-use. Crucially, paludiculture gets currently no direct payments or funding as it is currently not recognised as a form of agriculture (Wichtmann, 2016).

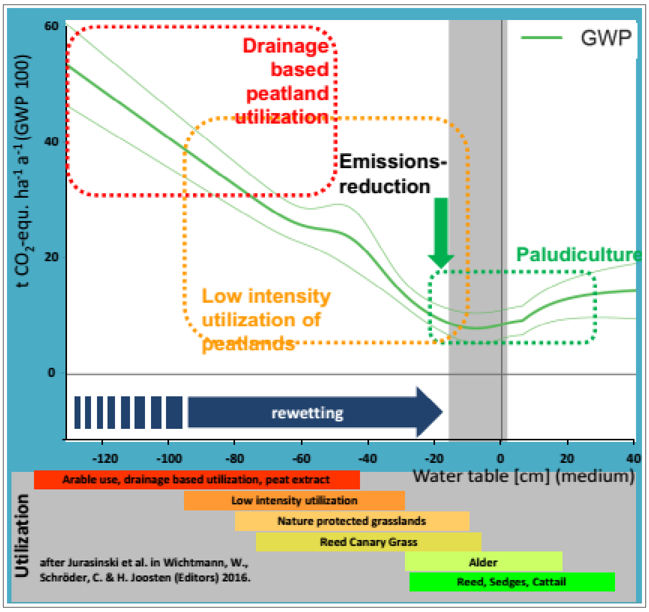

Fig. 6.4: Use of peatlands and greenhouse gas emissions, from Wichtmann et al. (2016)

Tourism

Ecotourism is becoming more important and well-prepared natural peatlands attract tourists who seek recreation and relaxation in these wildlife habitats. Installed pathways and information boards protects ground and vegetation and still gives insight into habitat specific information (Joosten et al., 2016). This also increases understanding of the importance of peatlands in the climate debate and peatland restoration processes. At the same time, tourism increases employment and economically benefits the local community (IUCN UK Peatland Programme, 2009).

Grazing

Restored peatlands might still be suitable for grazing of smaller ruminants (sheep, goats, game) during the summer months. Special attention has to be concentrated on the right stock to site ratio. Light grazing helps to reduce bushes and favours the growth of peatland vegetation (grazing pressure).

Brooks et al. (2014) provided the following suggested livestock densities:

Habitat	Livestock densities	Comments
Dry heath	1.5 – 3 / ha	Focuses on maintenance of heather stands
Wet heath	1 – 1.5 / ha	Focuses on maintenance of heather stands
Degraded Bog	0.25 – 0.37 / ha	Periodical control of bushes
Wet Bog	<0.25 / ha	Controlled grazing pressure on defined spots

Tab. 6.6: Suggested livestock densities per hectare on different restored peatland sites, modified from Brooks et al. (2014)

6.6) Communication

Fig. 6.5: Target audience during the preparation of restoration projects, from Schumann and Joosten (2008)

Farmers

Communication with farmers poses a significant challenge, as European policies and subsidies in agriculture are not yet satisfying in matters of peatland and climate friendly land-use alternatives. Transparency and open communication are obligatory to create a common identity. Some countries (e.g. Germany) have already put that into practice (Cris et al., 2014) and claimed incentives for peatland management. An interesting study has been conducted by Ferré et al. (2016) in which Swiss farmers were asked to show their agreement to restore peat soils based on a computer game. The results showed that agglomeration payments (defined by Wätzold and Drechsler (2014) as a payment "where landowners receive money only if conserved land parcels are spatially connected") is a promising possibility to increase the effectiveness of homogeneous payments, so that farmers get a bonus "on top". The study showed that 60% of high production farmers who are relatively independent on peat soil conservation for their economic future are willing to adopt extensive land use and peat conservation strategies when agglomeration payments are provided. This might also be the case in other countries where economic success within agriculture is primarily based on direct payments, so the possibility for promoting climate friendly peatland use is primarily based on governmental payments (Ferré et al., 2016). This is currently the only option to reduce profit setbacks due to lower production rates and lowered market prices for restored or conserved peatlands (Anzaldua and Gerdes, 2011).

Stakeholders and politics

Responsibility for peatland management extends across different sectors including stakeholders and politicians at the international, national and local levels. It is thus important to bring interests together and shape a basis for good communication. A transparent partnership from the early stages helps mitigating possible conflicts. (Cris et al., 2014) and makes the access to successful monetising easier (Karpowicz, 2011).

Local Communities

As already mentioned under tourism, restoring peatlands creates recreational areas. The local communities may profit by increasing employment possibilities and economic benefits. It is beneficial when people are able to identify themselves with peatland management and the positive climatic consequences. Additionally, Schumann and Joosten (2008) stated that “the success of a planned restoration project will depend on public support and acceptance”.

6.7) Hazards

Fire risks

On peatlands, one should be aware of peatland fires, of which hundreds to over thousand every year, mainly in eastern Europe. Peatland fires can be caused by any source of fire (e.g. lightnings, cigarettes, camp fires) on drained and dry soils. As already discussed in previous chapters, peat in drained peatland lost its water bearing capacity and consists to its greatest extent of pure carbon – the ignition capacity is enormous and often compared to gunpowder (Wetlands International, 2016). Peatland fires not only result in the loss of up to 50cm of peat soil and extreme release of organic CO_2 into the atmosphere – enormous clouds of dust are hazardous to local communities and cause several deaths every year. In 2010, the burning of a peatland near Moscow, Russia affected more than 50 000 lives severely. The economic losses from fire-fighting and related activities are a substantial expense factor for many countries. As natural peatlands are unlikely to burn, restoration lowers the risk of peat fires and its subsequent economic losses and hazards on local communities significantly. A rewetting project in Belarus led to an increasing downwards trend in fire related activities, saving the country about 1 million € annually (www.climaeast.eu, Pilot project in Belarus, acc. 06.01.17). The assessment of fire risks thus plays an important role in the management of degraded peatlands.

Inundation

Floods and inundations are an increasing natural hazard. Restoration of coastal and river-near peatlands not only contributes to climate change mitigation and climate friendly land-use, these areas might also act as polders for flood mitigation (Joosten et al., 2015).

6.7) Examples of successful restoration projects

Kieve Polder, Germany (Joosten et al., 2015)

The Kieve polder in north-east Germany has an area of approximately 65 ha of which 49ha has been used for agriculture (mainly high-intensity grassland). The thickness of the peat layer is 3m in average and the water table has been lowered to -70cm by drainage. The restoration project aims to rewet 54,4 ha, allowing agriculture only on border areas. Half of the area (25.5 ha) was inundated up to 20cm above surface level with a varying ground water level on the remaining site area. The total costs for rewetting of the Kieve polder amounted 501.375€ and the project was funded by the German Federal Environment Ministry and the German Federal Agency for Nature Conservation. Additional funding was gained through the voluntary carbon market under the project of "Moor Futures". Based on measurements and estimations, emissions for two post-rewetting land-use alternatives are as follows:

Land-use	Emissions in t CO_2 eq / yr	Emissions in t CO_2 eq for 50 yrs
Pre-restoration (intense grasslands)	1305.6	65 280
Post-restoration (Reed farming, forb meadows)	532.5	26 625

Tab. 6.7: Emissions from the baseline scenario and project scenario in Polder Kieve, Germany, modified from Joosten et al. (2015)

Estimations for emissions include methane spikes during the first 10 years after rewetting and show a significant decrease of emissions from the site. The yearly savings amount to 773.1 t CO_2 eq and during the total project time of 50 years, emissions can be reduced by 38655 t CO_2 eq. Selling of Moor Futures for the Kieve polder resulted in prices of 35€ per ton of CO_2 eq and so far, more than 300 000€ has been earned (Joosten et al., 2015).

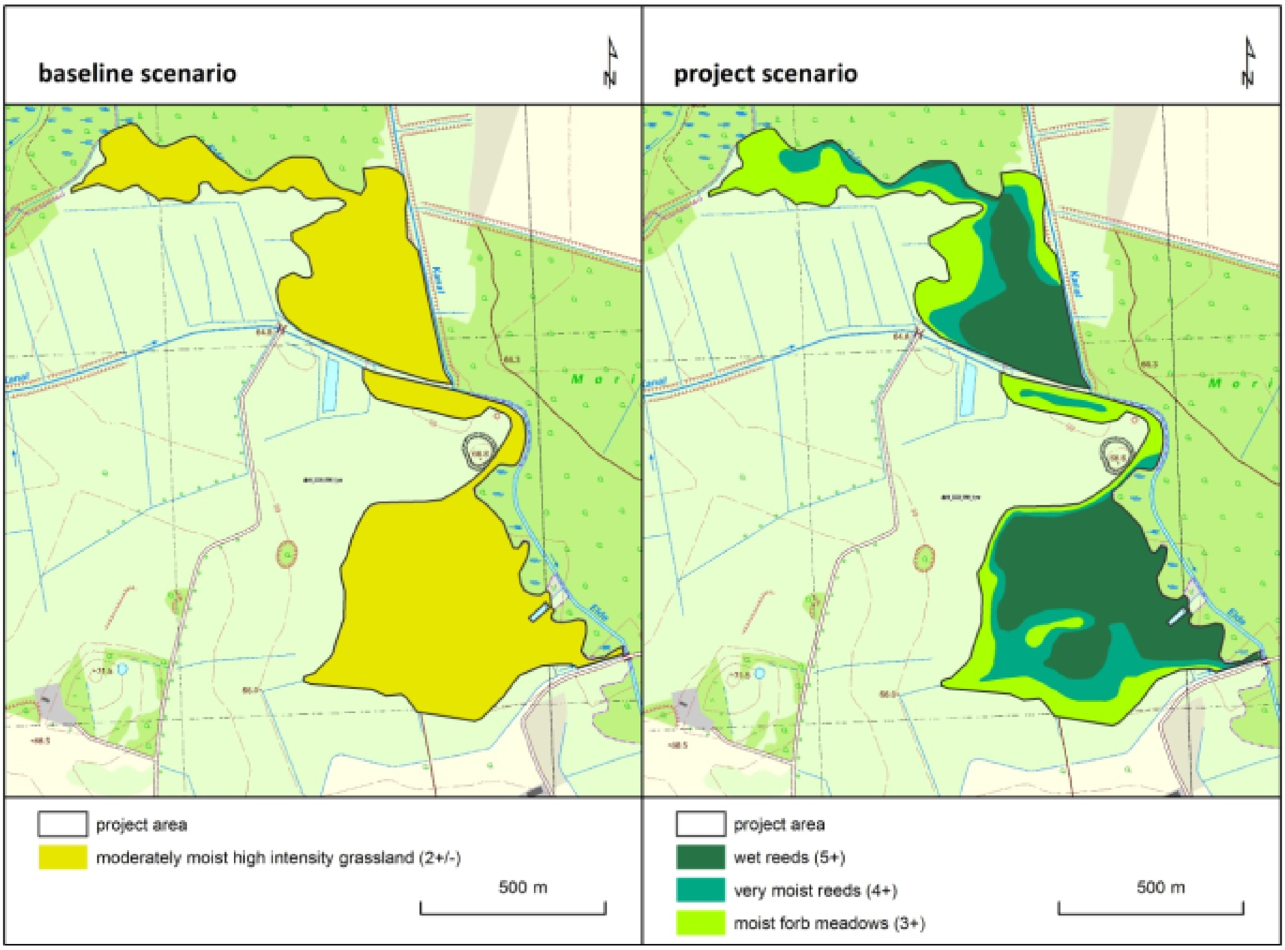

Fig. 6.6: Vegetation types in the baseline scenario and project scenario in Polder Kieve, Germany, taken from Joosten et al. (2015)

Belarus, UNDP-GEF Peatlands project (2006-2010), (http://www.climaeast.eu/clima-east-activities/pilot-projects/pilots-project-in-belarus)

Fig. 6.7: Grichino Starobinskoje - Largest fen restoration site in Belarus, photo taken from Karpowicz (2011)

Between 2006 and 2010, more than 20 sites equalling over 50 000 ha of drained peatlands have been restored in Belarus (Fenchuk et al., 2011). Peat extraction and intense agriculture were the main pre-restoration uses and the water table had been lowered to about - 0.7 to -1.0 meters (http://www.climaeast.eu/clima-east-activities/pilot-projects/pilots-project-in-belarus, accessed: 06.01.17). The restoration project was funded by the International Climate Initiative of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety through the KfW development bank, the APB-Birdlife Belarus, the environmental programme of the UN (UNDP) in Belarus, and the Ministry for Natural Resources and Environmental Protection of the Republic of Belarus (Succow-Stiftung, 2011).

The aim was to re-establish biodiversity, mitigate climate change and lower the risk of peatland fires. Other objectives were to reduce the loss of local livelihoods, such as berry picking, fishery and hunting, as well as to improve water conditions in the catchment areas (Succow-Stiftung, 2011). Costs were highly dependent on peatland sites and the complexity of the construction works. They ranged between 15 to 150€ per hectare with total costs of approximately 1.4 million € (Karpowicz, 2011; http://www.climaeast.eu/clima-east-activities/pilot-projects/pilots-project-in-belarus, accessed 06.01.17). As emissions are assumed to be reduced by 235 000 t of CO_2 eq annually on average over the next 50 years and the prevention of fire risks alone saves about 1 million € every year (http://www.climaeast.eu/clima-east-activities/pilot-projects/pilots-project-in-belarus, accessed: 06.01.17), the benefits of peatland restoration in Belarus clearly evident. As in the German exemplary site, carbon credits were offered on the voluntary carbon market.

Bellacorick, Ireland (Wilson et al., 2016)

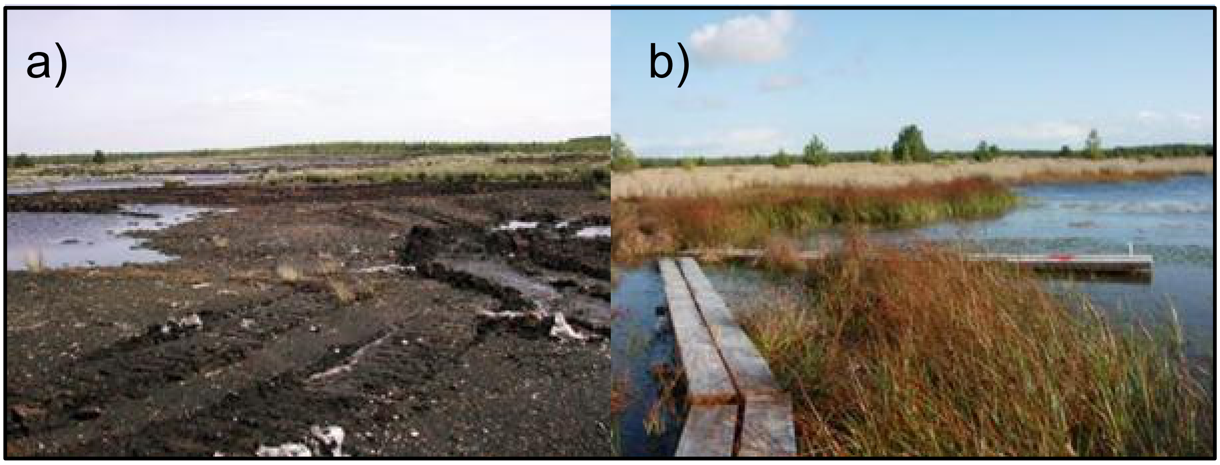

Fig. 6.8: Abandoned peatland in Bellacorick prior (a) and after (b) rewetting. Photos are taken in the same area, from Wilson et al. (2013)

Bellacorick is located in north-west Ireland in the county of Mayo. The site is a former blanket bog of 6500 ha and had been drained for peat extraction from 1961 to 2002 under the ownership of Bord Na Mona. After cessation of peat extraction, the area was dominated by 87% of bare peat, with the remaining part being open water (Wilson et al., 2016). In 2002 a restoration plan was outlined, aiming at the stabilisation of peat by re-establishing vegetation and overall natural conditions including gas exchange. As the remaining peat thickness was only about 50cm in average, technical planning included the creation of shallow pools beside blocking and damming of ditches and drainages (Wilson et al., 2016). The site was recolonised by three dominant vegetation communities: Juncus effusus, Eriophorum angustifolium and Sphagnum mosses (Wilson et al., 2013). Measurements from rewetted and still drained and bare peatland sites showed that restoration procedures at Bellacorick resulted in its successful re-establishment as a carbon sink. It has been calculated that emissions of 75 t CO_2 eq per hectare have now been mitigated by little more than basic rewetting actions (Wilson et al., 2012). Detailed emission measurement results are available in Wilson et al. 2013 and 2016. Annually carbon sequestration is under current estimates worth 118€ per hectare resulting in an overall value of 767 000€ per year (Wilson et al., 2016). The site at Bellacorick is an exemplar for sustainable management of closed down peat extraction sites and a successful communication example.

Konilamminsuo mire, Finland (Komulainen et al., 1999)

The Konilamminsuo mire is located in southern Finland, within the zonation of southern boreal coniferous forests. The site was drained for forestry in the early fifties and has naturally been a minerotrophic tall-sedge pine fen. Ditches have been relatively narrow with a spacing of 50m and 90cm of depth. Restoration procedures included primarily raising the water table by blocking of ditches as well as mechanical clear-cutting of the predominant forest on 1.1 ha. Measurements of gas fluxes were taken in the year prior restoration and in the two subsequent years. The results show that already by the second year after rewetting, CO_2 efflux rates had been halved compared to the remaining untreated plots of the site. CO_2-C balances were reported to vary between 162 to 283 g / m^2 / h. This study was conducted relatively early, before commercial restoration projects for the voluntary carbon market evolved, but it already shows the benefits of restoring peatlands drained for forestry aiming at climate change mitigation and general development towards pristine peatland characteristics

7) Mitigating climate change: Sinkpotential vs. sourcepotential calculations

For the purpose of defining the possibilities and contributions of climate change mitigation by restoring suitable European peatlands, we have to consider the facts that were worked out in the previous chapters. In general, degraded peatlands are sources of carbon, whereas intact peatlands act as sinks. Evaluation of the overall emission potential, leading to calculated global warming potential (GWP), is more complicated but generally indicates that restored peatlands still contribute to emissions of climate forcers to the atmosphere and therewith global warming – but usually in an alleviated form compared to degraded peatlands. This chapter aims at evaluating whether large-scale restoration of degraded peatlands in Europe is a reasonable and practical scenario of climate change mitigation or not, based on criteria for:

- Average carbon accumulation rates
- Average emission rates of climate forcers in CO_2 eq
- Average costs for restoration procedures

7.1) Data collection and methods

To calculate benefits for theoretical peatland restoration in Europe, it is essential to derive mean values of emission factors for boreal and temperate drained and restored peatlands from a wide range of scientifically accepted data sets. These have been reported in a large range of relevant literature and have for the purpose of this thesis been collected to get mean values that are able to represent the European average. All emission values have been converted to standardised t CO_2 eq ha^{-1} yr^{-1} , Mt CO_2 eq ha^{-1} yr^{-}, or Gt CO_2 eq ha^{-1} yr^{-1} where necessary. Area sizes are given in hectares and cost factors in Euros (€). Mathematical methods comprise only basic mathematics, no statistical calculations were needed.

7.2) Peatland criteria – Which peatlands are suitable?

Criteria for the right choice of degraded peatlands to restore are varied and not always straight forward. There are probably only a few areas which are perfectly suitable, so most restoration sites will include weighing up of pros and cons. In connection with the restoration management plan, projects should consider the following examples of criteria to define whether a peatland is suitable for restoration or not:

- **Ownership:** Would land need to be bought from private owners? How expensive is that and are the owners willing to sell?
- **Current vegetation and biodiversity:** Are there remaining peatland specific vegetation communities or do plants have to be re-established from the beginning? Are there intact peatlands in the surrounding area?
- **Minimum peat thickness:** Peat thickness should, by definition (see Box 3.1), be at least 30cm, often 50cm for projects
- **Current land use:** Is it actively agricultural (→ communication with local farmers) or are the peatlands abandoned after peat extraction or agricultural inefficiency?
- **Size and agglomeration:** It is often easier and cheaper to restore large areas at once than several small ones.
- **Surrounding landscape and land-use:** Would surrounding topography or drainage for agriculture disturb raising the water table? Would fertilisation affect the restored peatland chemistry due to water flow in the catchment area?
- **Water resources:** Is rewetting possible or has intense drainage of the area and surrounding area led to poor water resources? Are the chemical water conditions appropriate?
- **Costs:** Is funding by international and national conventions and programmes possible? Is funding by private stakeholders and the carbon market potentially attainable? → Financial management plan.

7.3) Atmospheric carbon dioxide without rewetting of peatlands

In 2008 the European total peatland area covered over 504 608 km^2 (equal to 50 460 800 ha) of which 219 637 km^2 (equal to 21 963 700 ha) are currently degrading (Joosten, 2009). Byrne et al. (2004) reported average values for CO_2 emissions from peatlands drained for agriculture, forestry or peat extraction ranging from 15 - 25 t CO_2 ha^{-1} yr^{-1}. Reported values for total emissions of climate forcers, given in CO_2 eq range from 30 - 60 t CO_2 eq ha^{-1} yr^{-1} for drainage based peatland utilisation (Wichtmann, 2016).

Every year, Europe's degrading peatlands emit between 0.33 – 0.55 Gt CO_2 per year and between 0.66 – 1.32 Gt CO_2 eq.

$$15 - 25 \text{ t } CO_2 \text{ ha}^{-1} \text{ yr}^{-1} \cdot 21\,963\,700 \text{ ha} = 0.33 - 0.55 \text{ Gt } CO_2 \text{ yr}^{-1}$$

$$30 - 60 \text{ t } CO_2 \text{ eq ha}^{-1} \text{ yr}^{-1} \cdot 21\,963\,700 \text{ ha} = 0.66 - 1.32 \text{ Gt } CO_2 \text{ eq yr}^{-1}$$

Calc. 7.1: Calculation of annual emissions (Co_2 and Co_2 eq) from currently degrading European peatlands

The following extrapolation scenarios are based on the case that nothing changes in the meantime, including the current area size of 21 963 700 ha of degrading peatlands.

Years	Emissions in Gt CO_2 since present	Emissions in Gt CO_2 eq since present
10	3.3 – 5.5	6.6 – 13.2
20	6.6 – 11.0	13.2 – 26.4
50	16.5 – 27.5	33.0 – 66.0
100	33.0 – 55.0	66.0 – 132.0

Tab. 7.1: Extrapolation of emissions (CO_2 and CO_2 eq) from currently degrading European peatlands for the next 100 years

7.4) Climate change mitigation scenarios: Sinkpotential vs. sourcepotential of European peatlands. Case studies of restoring 10% (20 %, 30%, 50%) of the total degrading area.

To define whether degrading peatlands will act as sinks or sources of carbon dioxide and what their effect on global warming potential and the atmospheric carbon reservoir will be depends on several emission factors.

Carbon sequestration

Carbon accumulation rates are expressed in LORCA (**L**ong-**T**erm-apparent-**R**ate-of-**C**arbon-**A**ccumulation) and have been reported to vary between 0.15 – 1.5 t C ha^{-1} yr^{-1} for Europe's boreal and temperate regions, strongly depending on vegetation, climate and peatland type (Joosten and Clarke, 2002; Höper, 2007; Tolonen and Turunen, 1996). These rates define the peatlands function as a sink for atmospheric carbon.

Emissions of carbon dioxide equivalents

The rate of emissions in CO_2 as well as emissions of CH_4 and N_2O, which both have a significantly stronger climate effect than CO_2 (see previous chapters), can be expressed as carbon dioxide equivalents. This results in a better comparability when discussing emissions of different gases. Methane for example is 23 times more powerful than carbon dioxide (Joosten, 2015) and this stronger effect on climate is included when converting into CO_2 equivalents.

Global warming potential (GWP)

Conversion of gas emission in carbon dioxide equivalents also gives the possibility to define the relative effect on climate warming for a defined time horizon - usually 20, 100 or 500 years (IPCC, 1995). The GWP of emissions from peatlands includes all relevant climate forcers (CO_2, CH_4, N_2O) and thus defines the relative long-term function of peatlands as a source of gases contributing to climate change.

Calculations

As already noted above, average emission rates for climate forcers and the GWP100 have been derived from several sources and the mean values have been summarised as follows:

Emissions in:	**CO_2**		**CH_4**		**GWP (100)**	
	Drained	Restored	Drained	Restored	Drained	Restored
t CO_2 eq ha^{-1} yr^{-1}	3.3	-7.8	1.3	8.5	3.9	1.8

Tab. 7.1: Summary of mean values for European temperate and boreal peatlands for drained and restored sites. Based on: Weldon et al. (2016), Strack et al. (2008), Byrne et al. (2004)

These mean values, the values for LORCA already provided as well as the data (in ha) of currently degrading peatlands in Europe (Chapter 7.3) provide the basis for all following calculations. I have included columns for the emission differences between those used for drainage based utilisation and restored peatlands. These differences relate to restored peatlands and shall highlight whether emission data are beneficial compared to those from drained ones and to what extent.

The following calculations aim to evaluate whether restoration of different percentages of European peatlands leads to advantages or disadvantages in mitigating climate change. It is kept as simple as possible to get the best overview. As the basic data represents averages from sixty well-known different sites (based on: Weldon et al. (2016), Strack et al. (2008), Byrne et al. (2004); see appendix III) to summarise emissions from European peatlands, emission data for particular peatlands might differ significantly. It should be observed that the calculated values for drained peatlands are to varying extents negligible in this context and only serve for better comparability, as by definition all of Europe's 21 963 700 ha of degraded peatlands are drained.

Extent of peatland restoration size	LORCA in Mt C yr^{-1} (ha · 0.15 – 1.5 t C ha^{-1} yr^{-1})			CO_2 in Mt CO_2eq yr^{-1} (ha · 3.3 (d) // -7.8 (r) t CO_2eq ha^{-1} yr^{-1})		
	Drained	Restored	Difference	Drained	Restored	Difference
10% (2196370 ha)	/	0.33 – 3.30	/	7.3	- 17.1	- 24.4
20% (4392740 ha)	/	0.66 – 6.60	/	14.5	- 34.0	- 48.5
30% (6589110 ha)	/	1.00 – 9.80	/	21.8	- 51.4	- 73.2
50% (10981850 ha)	/	1.70 – 16.48	/	63.2	- 85.7	- 148.9

Tab. 7.2: Theoretical values of carbon accumulation and CO_2 emissions from different drainage/restoration scenarios (in %) of peatlands. Emission factors are given in the equation: (d) = drained, (r) = restored. Values for drained peatlands of different extent are negligible and only serve for better comparability.

Extent of peatland restoration size	CH_4 in Mt CO_2 eq yr^{-1} (ha · 1.3 (d) // 8.5 (r) t CO_2 eq ha^{-1} yr^{-1})			GWP100 in Mt CO_2 eq yr^{-1} (ha · 3.9 (d) // 1.8 (r) t CO_2 eq ha^{-1} yr^{-1})		
	Drained	Restored	Difference	Drained	Restored	Difference
10% (2196370 ha)	2.9	18.7	+ 15.8	8.6	3.9	- 4.7
20% (4392740ha)	5.7	37.3	+ 31.6	17.1	7.9	- 9.2
30% (6589110 ha)	8.6	56.0	+ 47.4	25.7	11.8	- 13.9
50% (10981850 ha)	14.3	93.4	+ 79.1	42.8	19.8	- 23.0

Tab. 7.3: Theoretical values of the Global Warming Potential (100) and CH_4 emissions from different drainage/restoration scenarios (in %) of peatlands. Emission factors are given in the equation: (d) = drained, (r) = restored. Values for drained peatlands of different extent are negligible and only serve for better comparability.

7.5) Cost-benefit analysis

The costs of peatland restoration procedures have been elaborated in chapter 6.4. As the actual expense factors are highly depending on peatland type, size, damage and the country, there are huge differences between countries due to different salaries and average prices for arable land. The average costs include factors for land purchase in Germany, as well as costs for topsoil-removal in the Netherlands and Poland. The results (table 7.4) show that the average restoration costs for European countries range from 2135 – 7335€ per hectare, resulting in a mean value of 4735€. It has been reported by Joosten et al. (2015) that the financial benefits of one ton of avoided CO_2eq is ranging between 30 – 50€ and the subsequent financial benefits per year and hectare are assumed to be around 728€ (Joosten and Clarke, 2002; Höper, 2007).

Country	Cost ranges in € per hectare	Source
Germany	3000 – 5000 (incl. land purchase)	Förster and Schäfer (2009)
Poland	800 – 3100 (incl. topsoil removal)	Klimkowska et al. (2010)
The Netherlands	10000 – 30000 (incl. topsoil removal)	Klimkowska et al. (2010)
Belarus	15 - 150	Anzaldura and Gerdes (2011)
Ireland	400	Bord na Mona (2015)
Great Britain	235 - 11700	Moxey and Moran (2014)
Finland	500 - 1000	Virnes (2013)
Total average:	**2135 - 7335**	

Tab. 7.4: Overview about European restoration costs in Euro per hectare

Extent of peatland restoration size	Costs for restoration procedures in Euro (ha · 4735€)	Annual savings of costs for emissions in Euro (ha · 728€)	Profitability in years (after onset of continuous emissions ≈ 10y)
10% (2196370 ha)	10 399 811 950 €	1 598 957 360 €	6.5 years
20% (4392740 ha)	20 799 623 900 €	3 197 914 720 €	6.5 years
30% (6589110 ha)	31 199 435 850 €	4 796 872 080 €	6.5 years
50% (10981850 ha)	51 999 059 750 €	7 994 786 800 €	6.5 years

Tab. 7.5: Costs and profitability of large-scale peatland restoration

It can be assumed that 16.5 years after the onset of restoration procedures, emissions are relatively stable and the methane spike is moderated. The long-term financial benefits of selling carbon credits on the compliance or voluntary carbon market, with average prices of 30 – 50€ per ton CO_2 eq (Joosten, 2015) for projects with a life span of at least 50 years are as follows.

Extent of peatland restoration size	Remaining profit-able years	Avoided tons of CO_2 equivalents / yr	Benefits from selling carbon credits á 40€
10% (2196370 ha)	33.5 years	4 700 000	6 298 000 000 €
20% (4392740 ha)	33.5 years	9 200 000	12 596 000 000 €
30% (6589110 ha)	33.5 years	13 900 000	18 894 000 000 €
50% (10981850 ha)	33.5 years	23 000 000	31 490 000 000 €

Tab. 7.6: Benefits from selling carbon credits for the remaining profitable life-time of large-scale peatland restoration projects

8) Discussion

This thesis investigated whether large-scale restoration and re-establishment of natural conditions in degraded European peatlands might promote their natural ability to accumulate atmospheric carbon and therefore act as major carbon sinks in the context of climate change mitigation. The results reveal that peatlands are the only ecosystems that, in the right conditions, have the ability to permanently store carbon and therefore offer enormous potential to mitigate further global warming. The cost-benefit analysis clearly shows that large-scale restoration is an expensive but promising process, as indicated by the financial profitability after re-establishment of natural ecological conditions in connection with continuous emission reductions (table 7.5 and 7.6). It was further demonstrated that the feasibility is not only dependent on financial factors, but is largely dependent on three major determinants:

- First of all, international and national policies and governments have to acknowledge the general importance of peatlands and wetlands in the climate debate and support alternative land-use options (LULUCF) within their regulatory schemes (chapter 5).

- Secondly, cooperation and communication between stakeholders, local communities, landowners, farmers and national governments must be conducted in a transparent and open way. There is evidence that successful peatland and climate friendly farming under EU policies requires adjustments to the current frameworks and agricultural subsidies in order to give farmers incentives to switch to alternative land-use (chapter 6.6).

- Thirdly, international cooperation between peatlands and climate initiatives is essential, as transparency about data, results and limitations of conducted projects strongly increases the impact of techniques and measures within restoration management. These findings are supported by strikingly successful international projects such as those between Germany and Russia or Belarus, the NorBalWet initiative or ClimaEast (chapter 5, chapter 6.7).

These major determinants were supported by previous studies at the international level (Barthelmes et al., 2015; Wilson et al., 2016). The possibilities of peatland restoration as one of the easiest form of climate change mitigation have been widely accepted among experts (Joosten and Clarke, 2002; Joosten, 2006; Chapman et al., 2013).). This thesis identified that many initiatives with governmental support, such as those in Great Britain, Germany and Belarus, currently produce the best implementation of peatland conservation. Some management plans included very targeted additional objectives such as ecotourism or concepts of paludiculture, while others focused primarily on emission reductions. It became apparent that the better a network between stakeholders operates, the better the achieved results were (see restoration examples, chapter 6.7). To avoid misapprehension, from my point of view it is essential to involve all relevant parties already from the beginning in strategic management planning and treat these as equal partners for a common goal.

Furthermore, the results reveal that climate friendly peatland management offers a wide range of carbon (table 7.5 and 7.6) and non-carbon related (chapter 6.5) benefits. As highlighted by a variety of studies (e.g. Wichtmann, 2016; Höper et al., 2008, Joosten et al., 2016) alternative land-use is not only beneficial for reducing emissions, but also favours the local communities' livelihoods, the quality and abundance of water resources and significantly mitigates hazardous scenarios including their consequences such as peatland fires and floods (Beyer and Höper, 2015; Brooks et al., 2014).

Carbon related benefits have been highlighted in the cost-benefit calculations (table 7.5 and 7.6) of different large-scale restoration scenarios. The cost of restoration measures is not inconsiderable, with an average of 4735€ per hectare (table 7.4) , but the benefits from avoided emissions and the optional selling of CO_2 eqivalents on compliance and voluntary carbon markets offer great financial opportunities for peatland restoration projects. However, as chapter 5 described, regulations have to be refined. There are still barriers that complicate accreditation before accessing carbon markets. Especially for accessing markets under the Kyoto protocol, a change in law would be required (Reed et al., 2013) and not a deportation into agricultural responsibilities.

It was furthermore outlined that the potential of restored peatlands can be found in their capacity to reduce long-term global warming potentials compared to peatlands drained for agriculture or industry. Peatlands in natural conditions verifiably act as sinks for carbon as indicated by the provided calculations and data from other sources (e.g. Chapman et al., 2013; Wichtmann, 2015; Weldon et al., 2016; Wilson et al., 2016). On the other hand they also account for increased methane emissions compared to dry peatlands (Harpenslager et al., 2015). Successful methane management should include a water table below -10cm /-20cm (Couwenberg, 2009) of the surface as well as avoidance of inundation. An optimised water table is the prerequisite to keep methane emissions in restored peatlands as low as possible. The by Harpenslager et al. conducted study in 2015 proposed topsoil removal as a mitigation strategy to prevent climate warming through methane emissions from restored peatlands has to be discussed carefully. From my point of view, topsoil removal would only result in short-term benefits and generally misses the point of restoring natural conditions. As methane has a relatively short atmospheric lifetime compared to carbon dioxide, methane emissions in the context of peatland restoration should not be overrated in matters of long-term climate change mitigation.

However, the most interesting potential in peatland restoration can be found in the fact that the long-term global warming potential is significantly reduced compared to the data for drainage based peatland use. The results of this calculation not only confirm emission reductions but also point to the financial benefits that can be gained by reduced costs for emissions and selling of carbon credits on compliance and voluntary carbon markets. As European countries currently account for the second largest emissions from degraded peatlands in a global comparison (IPCC, 2014), the indication is given that every restoration scenario proposed in this thesis might lead to significant benefits on national and international economical and societal levels. As the data for the conducted calculations were derived from generally summarised mean values based on Weldon et al. (2016), Strack et al. (2008), Byrne et al. (2004), the results only have limited validity and thus only should be taken as trends within the wider topic. Anyhow, the results are in agreement with other recently conducted studies (Wilson et al. 2016; Jordan, 2016; Wichtmann, 2015; Chapman, 2013) and therewith confirm once more what has been recognised by politicians and experts, even if studies on gas exchange from peatlands after restoration are limited as also are large-scale restoration scenarios on European international level. Increased validity could be derived by sink- and source potential calculations for each individual European country. The data then should include regional, climatic and peatland type related differences. Consecutively deductive summarisation then could result in accurate prospects for the total European emission balance and the benefits that might be achieved by large-scale peatland restoration procedures.

9) Conclusion

In summary, this thesis emphasises that large-scale restoration and therefore re-establishment of the natural conditions of European peatlands is a powerful possibility for long-term climate change mitigation as well as directly for emission reductions from degraded peatlands used for agriculture, forestry or industry. These carbon benefits would not only help to meet the commitments of international and national climate change programmes but would also include financial profitability by selling carbon credits. Restoration costs vary significantly between the different European member states and should not be underestimated, but due to annual savings by emission reductions, these costs are counterbalanced 6.5 years after continuously stable emission reductions. Non-carbon benefits involve economic benefits on the national level as well as increasing livelihoods and hazard reduction at local community level.

Acknowledgements

I would like to express my sincere gratitude to my supervisor Ulrich Ranke, Göttingen University, for good advice with coffee and cake and above all for delivering insight into the world of natural disaster risk management. Special thanks also goes to my co-supervisor Patrick Crill, Stockholm's University, for critical support and help. Most of all I would like to express my eternal gratitude to my beloved kids Alec, Jimmy and Ylva for endless patience, love and a lot of welcome diversion. Those respecting the shadows recognise the direction towards the light, thank you Yannic! Furthermore I want to thank my dog Ian for sitting hundreds of hours beside my feet staring at me and therewith being so annoying that I really stayed tuned to writing. Last but not least I want to thank you, the reader. By reading these lines, you showed that you have read at least one page of this thesis and that is simply great.

Good times do not fall from heaven.
We create them ourselves; they are just hidden within our hearts

(Fjodor Dostojewskij, 1821-1881, "Das Gut Stepantschikowo")

References:

Abdalla, M., Hastings, A., Bell, M., Smith, J., Richards, M., Nilsson, M., Peichl, M., Lofvenius, M., Lund, M., Helfter, C., et al. (2014) Simulation of CO_2 and attribution analysis at six European peatland sites using the ECOSSE model, in: Water, Air and Soil Pollution, Volume 225, Issue 11, pp 2182-2182

Andriesse, J. (1988) Nature and management of tropical peat soils, FAO Soils Bulletin 59, published by the Soil Resources, Management and Conservation Service, FAO Land and Water Development Division, Rome, ISBN 92-5-102657-2

Anzaldua, G. and Gerdes, H. (2011) Restoring peatlands and applying concepts for sustainable management in Belarus, Ecologic Institute, Berlin

Altmann, M. (2008) Socio-economic Impact of the peat and growing media industry on horticulture in the EU, Report for EPAGMA by Co Concept, Luxembourg, pp 119, available at: http://coconcept.lu/fileadmin/Downloads/Socio_Economic_Study1.pdf

Artz, R. and Chapman, S. (2016) Peatlands – A summary of research outputs supported or facilitated by the environmental change programme of the Scottish government's portfolio of strategic research 2011-2016, James Hutton Institute, Aberdeen, Scotland, pp 1-24

Barthelmes, A., Couwenberg, J., Risaga, M., Tegetmeyer, C., Joosten, H. (2015) Peatlands and climate in a Ramsar context : A Nordic-Baltic perspective, TemaNord report 544, ISBN 978-9289341967

Barthelmes, A., Couwenberg, J., Joosten, H. (2009) Peatlands in national inventory submissions 2009 – An analysis of 10 European countries, Wetlands International, Ede, The Netherlands

Beyer, C. and Höper, H. (2015) Greenhouse gas exchange of rewetted bog peat extraction sites and a Sphagnum cultivation site in northwest Germany, in: Biogeosciences, Volume 12, pp 2101-2117

Bord na Mona (2015) Raised bog restoration project, leaflet, available at: www.bordnamona.ie%2Fwp-content%2Fuploads%2F2015%2F11%2FBNM-Raised-Bog-Restoration-Project.pdf&usg=AFQjCNGzt3IJeEmA_yc1XfYyDaWjDRbpQ&sig2=hnMn8_ZCLHbqK-b3i8F3sPg

Bragg, O. and Lindsay, R., eds. (2003) Strategy and action plan for mire and peatland conservation in central Europe, Wetlands International, Wageningen, The Netherlands, pp 94

Brooks, S., Stoneman, R., Hanlon, A., Thom, T. (2014) Conserving bogs – the management handbook, 2. ed, York: Yorkshire peat partnership, available at: http://issuu.com/peat123/docs/conserving_bogs

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), Germany (2015) Grundlagen der Kohlenstoffmärkte, available at: http://www.carbon-mechanisms.de/einfuehrung/grundlagen-der-kohlenstoffmaerkte/, accessed: 27.12.2016

Byrne K., Chojnicki B., Christensen T. (2004) EU peatlands: Current carbon stocks and trace gas fluxes, Carbo-Europe-GHG Concerted Action – Synthesis of the European Greenhouse Gas Budget Report 4/2004, University of Lund, Sweden, pp 58

Central European University (n.d.) Wetland types and classification, available at: http://www.personal.ceu.hu/students/03/nature_conservation/wwddetail/Types_classif.html accessed: 01.12.2016

Chapman, S., Artz, R., Donnelly, D. (2013) Carbon savings from peat restoration, ClimateXchange, Scotland

Chojnicki, B., Michalak, M., Acosta, M., Juszcak, R., Augustin, J., Drösler, M., Olejnik, J. (2010) Measurements of Carbon Dioxide Fluxes by Chamber Method at the Rzecin Wetland Ecosystem, Poland, in: Polish Journal of Environmental Studies, Volume 19, Issue 2, pp 283-291

Čivić, K. and Jones-Walters, L. (2010) Peatlands in ecological networks in Europe, ECNC-European Centre for Nature Conservation report 11/2010, available at: http://www.ecnc.org/uploads/2012/10/ecological-networks-in-europe-current-status-of-implementation.pdf

Čížková, H., Květ, J., Comín, F., Laiho, R., Pokorný, J., Pithart, D. (2013) Actual state of European wetlands and their possible future in the context of global climate change, in: Aquatic Sciences , Volume 75, Issue 1, pp 3–26

ClimaEast (n.d.) Clima East Activities, available at: http://www.climaeast.eu/clima-east-activities/pilot-projects and http://www.climaeast.eu/, accessed: 24.12.2016

ClimaEast (n.d.) Pilot project in Belarus, available at: http://www.climaeast.eu/clima-east-activities/pilot-projects/pilots-project-in-belarus, accessed: 06.01.2017

Clymo, R., Turunen, J., Tolonen, K. (1998) Carbon accumulation in peatland, in: Oikos, Volume 81, pp 368-388

Coelho, V. (2014) Threats to peatlands, Wetlands Internatonal, Ede, the Netherlands, pp 13

Couwenberg, J., Augustin, J., Michaelis, D., Wichtmann, W., Joosten, H. (2008) Entwicklung von Grundsätzen für eine Bewertung von Niedermooren hinsichtlich ihrer Klimarelevanz - Endbericht, Ernst-Moriz-Arndt-Universität Greifswald, Germany, available at: http://paludikultur.de/fileadmin/user_upload/Dokumente/pub/gest.pdf

Couwenberg, J. (2009) Methane emissions from peat soils, Wetlands International, Ede, the Netherlands

Couwenberg, J. (2011) Greenhouse gas emissions from managed peat soils: Is the IPCC guidance realistic?, in: Mires and Peat, Volume 8, pp 1–10

Couwenberg, J. and Fritz, C. (2012) Towards developing IPCC methane ‘emission factors’ for peatlands (organic soils), in: Mires and Peat, Volume 10, pp 1–17

Cris, R., Buckmaster, S., Bain, C., Reed, M. (2014) Global peatland restoration demonstrating SUCCESS, IUCN UK national committee peatland programme, Edinburgh, Scotland

Deutsche Gesellschaft für Moor- und Torfkunde e.V. (2016) available at: http://www.dgmtev.de/, accessed: 27.12.2016

Dierßen, K. and Dierßen, B. (2008) Moore, 2.ed, pp 230, Ulmer, Stuttgart, Germany

Dunn, C., and Freeman, C. (2011) Peatlands: our greatest source of carbon credits?, in: Carbon Management, Volume 2, Issue 3, pp 289-301

Ellison, D., Lundblad, M., Petersson, H. (2011) Carbon accounting and the climate politics of forestry, in: Environmental Science and Policy, Volume 14, pp 1062–1078

ESDAC – European Commission (n.d.) European Soil Database, available at: http://esdac.jrc.ec.europa.eu/, accessed 07.12.2016

European Commission (2016) First European Climate Change Programme, available at: https://ec.europa.eu/clima/policies/eccp/first_en, accessed: 25.12.2016

European Commission (2016) Second European Climate Change Programme, available at: https://ec.europa.eu/clima/policies/eccp/second_en, accessed: 25.12.2016

European Commission (2016) The EU Water framework directive – integrated river basin management for Europe, available at: http://ec.europa.eu/environment/water/water-framework/index_en.html, accessed: 25.12.2016

European Commission (2016) The EU Emissions Trading System (EU ETS), available at: http://ec.europa.eu/clima/policies/ets_en, accessed: 25.12.2016

European Commission (2016) Natura2000, available at: http://ec.europa.eu/environment/nature/natura2000/index_en.htm, accessed: 25.12.2016

European Environment Agency (2016) Annual European Union greenhouse gas inventory 1990–2014 and inventory report 2016, EEA Report No 15/2016, available at: http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2016

European Environment Agency (2016) EUNIS Habitat type search, available at: http://eunis.eea.europa.eu/habitats.jsp, accessed: 25.12.2016

European Environment Agency (2016) CAP at a glance, available at: https://ec.europa.eu/agriculture/cap-overview_en, accessed 25.12.16

FAO (n.d.) Mitigation of Climate Change in Agriculture (MICCA) Programme, available at: http://www.fao.org/in-action/micca/knowledge/peatlands-and-organic-soils/en/, accessed: 24.12.2016

FAO (n.d.) UN Climate Change Conference COP 21 - Paris, France, available at: http://www.fao.org/climate-change/international-fora/major-events/unfccc-cop-21/en/, accessed: 25.12.2016

Fechner, E. and Hemond H. (1992) Methane transport and oxidation in the unsaturated zone of a Sphagnum peatland, in: Global Biogeochemical. Cycles, Volume 6, Issue 1, pp 33–44

Fenchuk, V., Schaffer, N., Karpowicz, Z. (2011) Peatland restoration in Belarus: from grants to carbon credits, Presentation at the Stirling conference “Investing in Peatlands: Delivering Multiple Benefits”, Stirling, UK

Ferré, M., Engel, S., Gsottbauer, E., Müller, A. (2016) Can “agglomeration payments” induce sustainable management of peat soils in Switzerland?, Presentation, 18th Annual BIOECON Conference, Cambridge, UK, available at: www.bioecon-network.org%2Fpages%2F18th_2016%2FFerre.pdf&usg=AFQjCNFkJ5IpEUEnwNu7dyXx9DR1bPxVQQ&sig2=cIrGrpX_fnC6fpVVIF8wKA

Finnish Peatland Society (2015) The Society, available at: http://www.suoseura.fi/eng/index.html, accessed: 25.12.2016

Fleischer, E., Khashimov, I., Hölzel, N., Klemm, O. (2016) Carbon exchange fluxes over peatlands in Western Siberia: Possible feedback between land-use change and climate change, in: Science of the Total Environment, Volumes 545–546, pp 424–433

Förster, J. and Schäfer, A. (2009) Peatlands restoration in Germany – a win-win-win situation for climate protection, biodiversity, conservation and land use, Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz Mecklenburg-Vorpommern, available at: www.TEEBweb.org

Freibauer, A., Drösler, M., Gensior, A. and Schulze, E. (2009) Das Potenzial von Wäldern und Mooren für den Klimaschutz in Deutschland auf globaler Ebene, in: Natur und Landschaft, Volume 84, Issue 1, pp 20-25

Gorham, E. (1991) Northern Peatlands: Role in the carbon cycle and probable responses to climatic warming, in: Ecological Applications, Volume 1, Number 2, pp 182-195

Granberg, G., Mikkelä, C., Sundh, I., Svensson, B., Nilsson, M. (1997) Sources of spatial variation in methane emission from mires in northern Sweden: A mechanistic approach in statistical modelling, in: Global Biogeochemical Cycles , Volume 11, Issue 2, pp 135-150

Graves, A. and Morris, J. (2013) Restoration of fenland peatland under climate change, Report to the adaption subcommittee of the Committee on Climate Change, Bedford

Global Peatlands Initiative (2016) What is the global peatlands initiative?, available at: www.globalpeatlands.org, accessed: 25.12.2016

Harpenslager, S., van den Elzen, E., Kobx, M., Smolders, A., Ettwig, K., Lamers, L. (2015) Rewetting former agricultural peatlands: Topsoil removal as a prerequisite to avoid strong nutrient and greenhouse gas emissions, in: Ecological Engineering, Volume 84, pp 159-168

Hendriks, D., Huissteden, J., Dolman, A., van der Molen, M. (2007) The full greenhouse gas balance of an abandoned peat meadow, in: Biogeosciences, Volume 4, Issue 3, pp 411-424

Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., Troxler, T. for IPCC (2014) 2013 Supplement to the 2006 IPCC guidelines for national greenhouse gas inventories, IPCC, Geneva, Switzerland

Höper, H. (2007) Freisetzung von Treibhausgasen aus deutschen Mooren, in: TELMA, Volume 37, pp 85-116

Höper, H., Augustin, J., Cagampan, J., Drösler, M., Lundin, L., Moors, E., Vasander, H., Waddington, J., Wilson, D. (2008) Restoration of peatlands and greenhouse gas balances, in: Peatlands and climate change, edited by Strack, M., International peat society, Jyväskylä, Finland,, pp. 182-210

Höper, H. (2009) Moorschutz und Klimaschutz, Power Point presentation, 2. Moorkonferenz 13.09.2009, Osterkappeln, Germany, pp 25, available at: http://www.nlt.de/pics/medien/1_1250076994/Moorschutz_und_Klimaschutz-Dr._Heinrich_Hoeper.pdf

International Mire Conservation Group (2015) Global Peatland Database, available at: http://www.greifswaldmoor.de/global-peatland-database-en.html, accessed: 08.12.2016

International Mire Conservation Group (n.d) About IMCG, available at: http://www.imcg.net/, accessed: 24.12.2016

IPCC (1996) Climate change 1995: IPCC second assessment report, IPCC, Geneva, Switzerland, available at: https://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1

IPCC (2001) Climate change 2001: IPCC third assessment report, IPCC, Geneva, Switzerland available at: https://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1

IPCC (2014) Climate change 2014: IPCC fifth assessment report, IPCC, Geneva, Switzerland available at: https://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1

International Peatland Society (2015) IPS strategic plan 2016-2020, available at: http://peatsociety.org/, IPS Secretariat, Jyväskylä, Finland, accessed: 25.12.2016

Irish Peatland Conservation Council (2016) About us, available at: http://www.ipcc.ie/about-us/, accessed: 26.12.2016

IUCN UK Peatland Programme (n.d.) An introduction to restoration techniques, available at: http://www.iucn-uk-peatlandprogramme.org/peatland-code

Jones, R, Hiederer, R., Rusco, E., Montanarella, L. (2005) Estimating organic carbon in the soils of Europe for policy support, in: European Journal of Soil Science, Volume 56, Issue 5, pp 655–671

Joosten, H., and Clarke D. (2002) Wise use of mires and peatlands – Background and principles including a framework for decision-making., Internatonal Mire Conservaton Group and Internatonal Peat Society, Saarijärvi, Finland

Joosten, H. (2006) Moorschutz in Europa - Restauration und Klimarelevanz, Landesverband Niedersachsen, eds., in: BUND Moore in der Regionalentwicklung, Wagenfeld, Germany, pp 35- 43

Joosten, H., and Couwenberg. J. (2009) Are emission reductions from peatlands MRV-able?, Wetlands Internatonal, Ede, the Netherlands

Joosten, H. (2009) The Global Peatland CO_2 Picture. Peatland status and emissions in all countries of the World, Wetlands Internatonal, Ede, the Netherlands, available at: htp://tinyurl.com/yaqn5ya

Joosten, H. (2009) Peatland carbon opportunities: a new worldwide inventory, UNFCCC Belarus presentation, available at: https://unfccc.int/files/kyoto_protocol/application/pdf/belaruspresentation
021009.pdf&sa=U&ved=0ahUKEwiLoLHAucvRAhUkYZoKHSaKC-UQFggIMAI&client=internal-uds-cse&usg=AFQjCNGWd1vvNBKLC7Ahlia1Pp-zeDmqbQ

Joosten, H., Brust, K., Couwenberg, J., Gerner, A., Holsten, B., Permien, T., Schäfer,A., Tanneberger, F., Trepel, M., Wahren, A. (2013) MoorFutures®- Integration von weiteren Ökosystemdienstleistungen einschließlich Biodiversität in Kohlenstoffzertifikate – Standard, Methodologie und Übertragbarkeit in andere Regionen, BfN Federal Agency for Nature Conservation, eds., BfN-Skripten, Bonn, Germany

Joosten, H., Brust, K., Couwenberg, J., Gerner, A., Holsten, B., Permien, T., Schäfer, A., Tanneberger, F., Trepel, M., Wahren, A. (2016) MoorFutures®- Integration of additional ecosystems services (including biodiversity) into carbon credits : standard, methodology and transferability to other regions, 2.ed., BfN Federal Agency for Nature Conservation, eds., BfN-Skripten, Bonn, Germany

Jordan, S. (2016) Greenhouse gas emissions from rewetted extracted peatlands in Sweden, doctoral thesis, Acta Universitatis Agriculturae Sueciae, Swedish University of Agricultural Sciences, Uppsala, Sweden, 2016:102

Karpowicz, Z. (2011) Climate and biodiversity projects in Belarus and Ukraine: Re-wetting degraded peatlands, Presentation, Royal Society for the Protection of Birds

Keddy, P. (2010) Wetland Ecology: Principles and Conservation, 2.ed, Cambridge University Press, Cambridge, pp 497, ISBN 978-0521739672

Klimkowska, A., Dziera, P., Brezinska, K., Kotowski, W., Medrzycki, P. (2010) Can we balance the high costs of nature restoration with the method of topsoil removal? Case study from Poland, in: Journal for Nature Conservation, Volume 18, pp 202-205

Korhola, A., Alm, I., Tolonen, K., Turunen, J., Jungner, H. (1996) Three dimensional reconstruction of carbon accumulation and CH_4 emission during nine millennia in a raised mire, in: Journal of Quaternary Science, Volume 2, pp 161-165
Lappalainen, E. (1996) Global peat resources, International Peat Society and Geological Survey of Finland, Espoo, Finland

Malone, S. and O`Connell, C. (2009) Ireland's peatland conservation action plan 2020 – halting the loss of peat and biodiversity, Irish Peatland Conservation Council, Kildare, Ireland

Martikainen, P., Nykänen, H., Crill, P., Silvola, J. (1993) Effect of lowered water table on nitrous oxide fluxes from northern peatlands, in: Nature, Volume 366, pp 51-53

Mathijssen, P., Tuovinen, J., Lohila, A., Aurela, M., Juutinen, S., Laurila, T., Niemelä, E., Tuittila, E., Väliranta, M. (2014) Development, carbon accumulation and radiative forcing of a subarctic fen over the Holocene, in: The Holocene, Volume 24, Issue 9, pp 1156-1166

Metla (2015) Finland – the peatland capital of the world, Natural resources institute Finland, available at: http://www.metla.fi/tutkimus/suotutkimus/tausta-en.htm, accessed: 19.12.2016

Metzger, C., Jansson, P., Lohila, A., Aurela, M., Eickenscheidt, T., Belelli-Marchesini, L., Dinsmore, K., Drewer, J., van Huissteden, J., Drösler, M. (2015) CO_2 fluxes and ecosystem dynamics at five European treeless peatlands – merging data and process oriented modelling, in: Biogeoscience, Volume 12, pp 125-146

Ministry of Forests, Lands and Natural Resource Operations British Columbia (n.d.) A glossary of wetland terminology, available at: https://www.for.gov.bc.ca/hre/becweb/downloads/downloads_wetlands/a%20glossary%20of%20wetland%20terminology.pdf, accessed: 01.12.2016

Minkkinen, K., Byrne, K., Trettin, C. (2008) Climate impacts of peatland forestry, in: Peatlands and climate change, edited by Strack, M., International peat society, Jyväskylä, Finland, pp 98-122

Mitsch, W. and Gosselink, J. (1993) Wetlands, 2nd ed., John Wiley, New York, ISBN 978-0442008055

Montanarella, L., Jones, R., Hiederer, R. (2006) The distribution of peatlands in Europe, in: Mires and Peat, Volume 1, Article 1

Moxey, A. and Moran, D. (2014) UK peatland restoration: Some economic arithmetic, in: Land economy working paper series, Number 79

Nordic Baltic Wetlands Initiative (n.d.) Our wetlands, available at: http://www.norbalwet.org/our-wetlands/ accessed: 24.12.2016

Nordic Baltic Wetlands Initiative (n.d.) About NorBalWet, available at: http://www.norbalwet.org/about-norbalwet/, accessed: 24.12.2016

O`Sullivan, R. and Emmer, E. (2011) Selling peatland rewetting on the voluntary carbon market, in: Tanneberger, F. and Wichtmann, W., eds., Carbon Credits from peatland rewetting. Climate – biodiversity – land use, Stuttgart, Schweizerbart Science publishers, pp 94–99

O`Sullivan, R., von Unger, M., Tapio-Biström, M. (2012) Finance options, in: Peatlands – guidance for climate change mitigation through conservation, rehabilitation and sustainable use, 2.ed., Joosten, H., Tapio-Biström, M., Tol, S., eds., FAO and Wetlands International, Rome, pp 23-34

Paappanen, T. and Leinonen, A. (2005) Fuel peat industry in EU, country reports – Finland, Ireland, Sweden, Estonia, Latvia, Lithuania, VTT project report, PRO2/P2079/05 , available at: www.warum-torf.info%2Fdownload%2Ffuel-peat-industry-in-eu&usg=AFQjCNE657_3mjz8d68BvuVjQPezE8T2GQ&sig2=D_K3LoefobsVGuDn8EgvfQ&bvm=bv.144224172,d.bGg

Parish, F., Sirin, A., Charman, D., Joosten, H., Minaeva, T., Silvius, M., eds. (2007) Assessment on peatlands, biodiversity and climate change, Global Environment Centre, Kuala Lumpur and Wetlands Internatonal, Wageningen, pp 179

Peat Resources Limited (2009) Long term sustainable biomass fuel, presentation at the Environmental Management and Engineering 2009 conference in Banff, Alberta, Canada, available at: www.peatresources.com%2Fdox%2FBanff_July_2009.pdf&usg=AFQjCNHW-vhi2KghDGVH63KfuLWMkb8tXg&sig2=_W3rwbUVUhk1L7m7zJYBuQ&bvm=bv.144224172,d.bGg&cad=rja

Pluchon, N., Hugelius, G., Kuusinen, N., Kuhry, P. (2014) Recent paludification rates and effects on the total ecosystem carbon storage in two boreal peatlands of Northeast European Russia, in: The Holocene, Volume 29, Issue 9, pp 1126-1136

Quaschning, V. (2010) Renewable energy and climate change, 1. ed., John Wiley & Sons Ltd, Chichester, pp 344, ISBN 978-0-470-74707-0

Quinty, F. and Rochefort, L. (2003) Peatland Restoration Guide, 2. ed, Canadian sphagnum peat moss association, Quebec, pp 1-106

Ramsar Convention Secretariat (2007) Ramsar handbooks for the wise use of wetlands, 3rd edition, Ramsar Convention Secretariat, Gland, Switzerland, available at: http://archive.ramsar.org/cda/en/ramsar-documents-guidelines-strategic-framework-and/main/ramsar/1-31-105%5E20823_4000_0__, accessed: 02.12.2016

Ramsar Convention Secretariat (2016) An Introduction to the Ramsar Convention on Wetlands, 7th ed., Ramsar Convention Secretariat, Gland, Switzerland, available at: http://www.ramsar.org/news/new-edition-of-the-ramsar-handbooks

Ramsar Convention Secretariat (2016) The list of wetlands of international importance, Ramsar Convention Secretariat, Gland, Switzerland, available at:http://www.ramsar.org/document/the-list-of-wetlands-of-international-importance-the-ramsar-list

Reed, M., Bonn, A., Evans, C., Joosten, H., Bain, C., Farmer, J., Emmer, I., Couwenberg, J., Moxey, A., Artz, R., Tanneberger, F., Von Unger, M., Smyth, M., Birnie, R., Inman, I., Smith, S., Quick, T., Cowap, C., Prior, S. (2013) Peatland Code research project, Final Report, Defra, London, available at: http://randd.defra.gov.uk/Default.aspxMenu=Menu&Module=More&Location=None&ProjectID=18642

Rydin, J. and Jeglum, J. (2013) The biology of peatlands, 2.ed., Oxford University Press, Oxford, ISBN 978-0199603008

Schäfer, A. (2009) Moore und Euros – die vergessenen Millionen, in: Archiv für Forstwesen und Landschaftsökologie, Volume 43, pp 156-160

Schmilewski, G. (2008) Peat Covers 77 Percent of the Growing Media Produktion in the EU, Peatlands International report, 1/2008

Schumann, M. and Joosten, H. (2008) Global peatland restoration manual, International Mire Conservaton Group, available at: htp://www.imcg.net/media/download_gallery/books/gprm_01.pdf

Schwill, S., Haberl, A., Strauss, A. (2010) Greenhouse gas emissions of peatlands. Methodology for the assessment of climate relevance – case study Zehlau peatland, Michael Succow Foundation, Greifswald, Germany

Similä, M., Aapala, K., Penttinen, J., eds. (2014) Ecological restoration in drained peatlands – best practices from Finland, Metsähallitus, Natural Heritage Services, Vantaa, Finland

Society of Wetland Scientists (n.d.) About the society of wetland scientists, available at: http://sws.org/About-SWS/overview.html, accessed: 25.12.2016

Ständiger Ausschuss für Geographische Namen – StAGN (n.d.) available at: www.stagn.de , accessed: 07.12.2016

Strack, M., ed. (2008) Peatlands and Climate Change, Internatonal Peat Society, Jyväskylä, Finland, pp 223

Succow, M. (08.11.2006) Klimafaktor Moor – Bilanzen wachsender und entwässerter Moore, Potsdamer Klimakonferenz 2006, available at: www.pik-potsdam.de/~stock/potsdam2006-11-08/2006-11-08_pik_suckow.pdf, accessed: 09.12.2016

Succow Foundation (2010) Peatland Conservation through International Climate Policy Mechanisms, available at: http://www.succow-stiftung.de/peatland-conservation-through-international-climate-policy-mechanisms.html, accessed: 26.12.2016

Tanneberger, F., and Wichtmann W., eds. (2011) Carbon credits from peatland rewetting. Climate – biodiversity – land use. Science, policy, implementation and recommendations of a pilot project in Belarus, Schweizerbart Science Publishers, Stuttgart, pp 223, ISBN: 978-3-510-65271-6

Tarnocai, C., and Stolbovoy, V. (2006) Northern peatlands: Their characteristics, development and sensitivity to climate change, in: Martini, I., Martinez Cortizas, A., and Chesworth, W., eds., Peatlands: Evolution and Records of Environmental and Climate Changes, Amsterdam, Netherlands, Elsevier B.V., pp 17–51

Tolonen, K. and Turunen, J. (1996) Accumulation rates of carbon mires in Finland and implications for climate change, in: The Holocene, Volume 6

Trepel, M. (2000) Quantifizierung der Stickstoffdynamik von Ökosystemen auf Niedermoorböden mit dem Modellsystem WASMOD, in: EcoSys Supply ,Volume 29, pp 140

Trepel, M. (2008) Zur Bedeutung von Mooren in der Klimadebatte - Jahresberichte des Landesamtes für Natur und Umwelt des Landes Schleswig-Holstein 2007/08, pp 61-74, available at: https://www.umweltdaten.landsh.de%2Fnuis%2Fupool%2Fgesamt%2F-jahrbe07%2FZur%2520Bedeutung%2520von%2520Mooren.pdf&usg=AFQjCNGE2RSehsEv2urzLvhqLhRfGbTZ8A&sig2=_j6NUuXt1bBXVS5o6_j2mw

Turunen, J., Tomppo, E., Tolonen K., Reinikainen, A. (2002) Estimating carbon accumulation rates of undrained mires in Finland – application to boreal and subarctic regions, in: The Holocene, Volume 12, Issue 1, pp 69-80

UNESCO (n.d.) World Heritage List, available at: http://whc.unesco.org/en/list/, accessed: 25.12.2016

UNESCO (n.d.) Tentative List, available at: http://whc.unesco.org/en/tentativelists/, accessed: 25.12.2016

United Nations Framework Convention on Climate Change (n.d.) The Kyoto Protocol, available at: http://unfccc.int/kyoto_protocol/items/2830.php and http://unfccc.int/essential_background/items/6031.php, accessed: 23.12.2016

United Nations Framework Convention on Climate Change (n.d.) Emission trading, available at: http://unfccc.int/kyoto_protocol/mechanisms/emissions_trading/items/2731.php, accessed: 23.12.16

United Nations Framework Convention on Climate Change (n.d.) The Paris Agreement, available at: http://unfccc.int/paris_agreement/items/9485.php, accessed: 25.12.2016

United Nations Framework Convention on Climate Change (n.d.) Marrakech Climate Change Conference - November 2016, available at: http://unfccc.int/meetings/marrakech_nov_2016/meeting/9567.php, accessed: 25.12.2016

Vepraskas, M. and Craft, C. (2016) Wetland Soils: Genesis, Hydrology, Landscapes and Classification, 2. ed, CRC Press, Boca Raton

Verified Carbon Standard (n.d.) www.v-c-s.org, accessed: 27.12.2016

Virnes, P. (2013) Peatland restoration in Finland – 25 years of practise makes an expert, Metsähallitus, Natural Heritage Services, Vantaa, Finland

Vitt, D. (2006) Functional characteristics and indicators of boreal peatlands, in: Wieder, R., Vitt, D., eds., Boreal Peatland Ecosystems, Springer, Berlin and Heidelberg, Germany, pp 9-24

Wätzold, F. and Drechsler, M. (2014) Agglomeration payment, agglomeration bonus or homogeneous payment?, in: Resource and Energy Economics, Volume 37, pp 85-101

Weiske, A. (2007) MECAP: Potential for carbon sequestration in European agriculture, 6th framework programme priority 8: Policy-Oriented Research, Impact of Environmental Agreements on the CAP, available at: http://www.ieep.eu/work-areas/agriculture-and-land-management/future-of-the-cap/2007/02/meacap-potential-for-carbon-sequestration-in-european-agriculture, Institute for European environmental policy

Weldon, S., Parmentier, F., Grønlund A., Silvennoinen, H (2016) Restaurering av myr. Potensialet for karbonlagring og reduksjon av klimagassutslipp, NIBIO rapport, Volume 2, Number 113

Wetlands International (2014) Briefing paper: Accelerating action to save peat for less heat!, available at: https://www.wetlands.org/publications/briefing-paper-accelerating-action-to-save-peat-for-less-heat/, Wetlands International, Wageningen, The Netherlands

Wetlands International (n.d.) About us, available at: https://www.wetlands.org/about-us/ , Wetlands International, Wageningen, The Netherlands, accessed: 24.12.2016

Wetlands International (n.d.) Peatland Treasures, available at: https://www.wetlands.org/our-approach/peatland-treasures/ ,Wetlands International, Wageningen, The Netherlands, accessed: 24.12.2016

Wetlands International (2016) Restoring peatlands in Russia – for fire prevention and climate change mitigation, Video, available at: https://www.youtube.com/watch?v=QZ5qu_nPHYM, accessed: 07.01.2017

Wichtmann, W. (2016) Challenges for peatland utilisation under recent EU framework conditions, Presentation, Peatland EU workshop April 2016, pp 1-17

Wilson, D., Farrell, C., Fallon, D., Moser, G., Müller, C. & Renou-Wilson, F. (2016) Multi-year greenhouse gas balances at a rewetted temperate peatland, in: Global Change Biology, Volume 22, Issue 12, pp 4080–4095

Wüst-Galley, E., Mössinger, E., Leifeld, J. (2016) Soil carbon loss in drained forested peatlands, in: Mires and Peat, Volume 18, pp 1-22

Zhang L., Sun X., Tian Y., Gong X. (2013) Composted Green Waste as a Substitute for Peat in Growth Media: Effects on Growth and Nutrition of Calathea insignis, PLoS ONE, Volume 8, Issue 10

Appendices

The tables in appendix I supplement the information in chapter 3.3 about the distribution of peatlands in Europe.

Appendix II supplements the information given in chapter 3.5 about usage of drained European peatlands for forestry, agriculture, peat mining and residual.

The data provided in appendix III are the base for calculations aiming at evaluating the question whether restoration of different percentages of European peatlands leads to advantages or disadvantages in mitigating climate change in chapter 7. The purpose was to summarize and derive a mean value for emissions from European peatlands based on those 60 well-known sites.

Appendix I

Joosten, H. (2009) The Global Peatland CO_2 Picture. Peatland status and emissions in all countries of the World, Wetlands Internatonal, Ede, the Netherlands

Country list of CO_2 emissions from degraded peatlands EUROPE

1990

Country/area	Area of country /area	Peatland area 1990	Peat carbon stock 1990	Forested peatland area 1990	Emissions from 1990 peatland drained for agriculture before 1990	Emissions in 1990 from 1990 peatland drained for forestry before 1990	Emissions in 1990 from 1990 peatland drained for peat extraction before 1990	Emissions in 1990 from 1990 peatland drained for other purposes before 1990	Emissions in 1990 from peat from non-forested peatland	Total degrading peatland area in 1990	Emissions from peat extracted in 1990	Total emissions in 1990 from degrading peat
EUROPE	km²	km²	Mton C	km²	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	km²	not included	Mton CO_2/a
Albania	28 748	179	18	0	0.6	0	0	0	0.6	175		0.6
Andorra	468	5	0.5	0	0.003	0	0	0	0.003	1		0.003
Austria	83 858	200	20	10	0.3	0.02	0.02	0	0.3	120		0.3
Azores	2 335	3	0.3	0	0	0	0	0	0	0		0
Belarus	207 595	23 976	1 320	6 000	27.1	7.7	0.6	6	33.7	18 050		41.3
Belgium	30 528	160	16	11	0.3	0.02	0.08	0	0.3	160		0.3
Bosnia & Herz.	51 129	150	15	0	0.4	0	0	0	0.4	140		0.4
Bulgaria	110 994	120	7	1	0.2	0	0.008	0.01	0.2	90		0.2
Channel Islands	205	10	1	0	0.03	0	0	0	0.03	10		0.03
Croatia	56 510	2	0.2	0	0.003	0	0	0	0.003	1		0.003
Czech Republic	78 864	270	27	90	0.3	0.2	0.05	0	0.3	220		0.5
Cyprus	9 251	1	0.1	0	0	0	0	0	0	0		0
Denmark	43 094	1 400	98	750	1.5	1.45	0.08	0	1.6	1 375		3.03
Estonia	45 227	10 000	1 000	2 000	7.5	6	0.50	0	8.0	6 330		14.0
Faroe Islands	1 400	30	3	0	0.008	0	0.003	0	0.01	6		0.01
Finland	338 145	85 000	5 320	60 000	11.9	39.6	0.7	0	12.5	61 900		52.1
France	543 965	1500	150	50	2.5	0.2	0.02	0	2.5	1 115		2.7
FYRO Macedonia	25 713	30	3	15	0.06	0	0	0	0.06	25		0.06
Germany	356 970	18 000	2 200	2 600	32.5	2	1.2	0	33.7	14 800		35.7
Gibraltar	6	0	0	0	0	0	0	0	0	0		0
Greece	131 957	71	7	1	0.14	0	0.003	0.003	0.1	57		0.1
Hungary	93 030	330	33	0	0.8	0	0.03	0	0.8	320		0.8
Iceland	103 000	14 000	650	40	17.5	0.03	0	0.01	17.5	7 050		17.5
Ireland	70 273	11 500	1 250	260	8.9	0.5	1.1	0	10.0	4 558		10.5
Isle of Man	572	0	0	0	0	0	0	0	0	0		0
Italy	301 323	200	20	10	0.4	0	0	0	0.4	100		0.4
Jan Mayen	373	0	0	0	0	0	0	0	0	0		0
Latvia	63 700	6 600	660	700	3.1	1.4	0.6	0	3.7	2 330		5.1
Liechtenstein	160	1	0.1	0	0.003	0	0	0	0.003	1		0.003
Lithuania	65 300	3 520	352	1 250	3.1	2.5	0.3	0	3.4	2 680		5.90

INTERNATIONAL MIRE CONSERVATION GROUP

ERNST MORITZ ARNDT UNIVERSITÄT GREIFSWALD

Wissen lockt. Seit 1456

WETLANDS INTERNATIONAL

2008

Peatland area 2008	Peat carbon stock 2008	Forested peatland area 2008	Emissions in 2008 from 2008 peatland drained for agriculture before 2008	Emissions in 2008 from 2008 peatland drained for forestry before 2008	Emissions in 2008 from 2008 peatland drained for peat extraction before 2008	Emissions in 2008 from 2008 peatland drained for other purposes before 2008	Emissions from peat from non-forested peatland 2008	Total degrading peatland area 2008	Emissions from peat extracted in 2008	**Total emissions from degrading peat 2008**	Total technically possible future emissions	**Country/area**
km²	Mton C	km²	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	km²	not included	**Mton CO_2/a**	Mton CO_2	**EUROPE**
163	14.9	0	0.6	0	0	0	0.6	160		**0.6**	49	Albania
4.9	0.5	0	0.003	0	0	0	0.003	1		**0.003**	1.6	Andorra
189	18.6	10	0.25	0.02	0.02	0	0.3	120		**0.3**	61	Austria
3	0.3	0	0	0	0	0	0	0		**0**	1.0	Azores
22 352	1 305	7 000	27.1	7.7	0.6	6	33.7	18 050		**41.3**	4 299	Belarus
146	14.3	9	0.2	0.02	0.08	0	0.3	160		**0.3**	47	Belgium
137	13.3	0	0.32	0	0	0	0.3	127		**0.3**	44	Bosnia & Herz.
112	5.9	0	0.16	0	0	0.01	0.2	70		**0.2**	20	Bulgaria
9.1	0.9	0	0.02	0	0	0	0.02	9		**0.02**	2.9	Channel Islands
1.9	0.2	0	0.0	0	0	0	0.002	0.9		**0.002**	0.6	Croatia
250	24.3	90	0.3	0.2	0.05	0	0.3	220		**0.5**	80	Czech Republic
1	0.1	0	0	0	0	0	0	0		**0**	0.3	Cyprus
1 276	73.6	750	1.5	1.5	0.08	0	1.6	1 375		**3.0**	243	Denmark
9 430	919	2 000	7.5	1.6	0.5	0	8.0	4 900		**9.6**	3 029	Estonia
29.5	2.9	0	0.01	0	0.003	0	0.01	6		**0.01**	10	Faroe Islands
79 429	5 294	60 000	7.5	41.6	0.9	0	8.4	63 250		**49.9**	17 438	Finland
1 400	137	50	2.5	0.2	0.03	0	2.5	1 120		**2.7**	450	France
27.8	2.7	15	0.05	0	0	0	0.05	20		**0.05**	9	FYRO Macedonia
16 668	2 018	2 600	30	2	0	0	30	13 000		**32**	6 646	Germany
0	0	0	0	0	0	0	0	0		**0**	0	Gibraltar
66	6.4	1	0.1	0	0.003	0	0.1	54		**0.1**	21	Greece
301	28.8	0	0.7	0	0.03	0	0.7	290		**0.7**	95	Hungary
13 366	564	40	17.5	0.03	0	0	17.5	7 040		**17.5**	1 857	Iceland
11 090	1 130	200	6.4	0.2	1.7	0	8	3 740		**8.2**	3 722	Ireland
0	0	0	0	0	0	0	0	0		**0**	0	Isle of Man
191	18.3	10	0.35	0	0	0	0.4	100		**0.4**	60	Italy
0	0	0	0	0	0	0	0	0		**0**	0	Jan Mayen
6 390	635	700	2.3	1.4	0.6	0	2.8	1 980		**4.2**	2 092	Latvia
0.9	0.1	0	0.003	0	0	0	0.003	1		**0.003**	0.3	Liechtenstein
3 279	323	1 300	3.3	2.6	0.2	0	3.5	2 740		**6.1**	1 064	Lithuania

Country list of CO_2 emissions from degraded peatlands EUROPE

1990

Country/area	Area of country /area	Peatland area 1990	Peat carbon stock 1990	Forested peatland area 1990	Emissions from 1990 peatland drained for agriculture before 1990	Emissions in 1990 from 1990 peatland drained for forestry before 1990	Emissions in 1990 from 1990 peatland drained for peat extraction before 1990	Emissions in 1990 from 1990 peatland drained for other purposes before 1990	Emissions in 1990 from peat from non-forested peatland	Total degrading peatland area in 1990	Emissions from peat extracted in 1990	Total emissions in 1990 from degrading peat
EUROPE (ctd)	km^2	km^2	Mton C	km^2	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	km^2	not included	Mton CO_2/a
Luxembourg	2 586	3	0.3	1	0.005	0.002	0	0	0.005	3		0.007
Malta	316	0	0	0	0	0	0	0	0	0		0
Moldova	33 700	10	1	0	0.02	0	0	0	0.02	9		0.02
Monaco	2	0	0	0	0	0	0	0	0	0		0
Netherlands	41 526	3 770	377	117	8.6	0	0.2	0	8.8	3 550		8.8
Norway	385 639	30 000	2 250	2 400	2.1	1.6	0.3	0	2.4	3 495		4.1
Poland	312 684	12 500	1 000	21 000	20	4	1.2	0	21.2	10 800		25.2
Portugal	92 345	20	2	1	0.05	0	0.003	0	0.06	16		0.06
Romania	237 500	1 000	100	10	1	0	0.03	0	1.0	420		1.0
Russia European part	3 477 000	213 000	21 300	50 000	85	58	132	0	217	151 000		275
San Marino	61	0	0	0	0	0	0	0	0	0		0
Serbia and Montenegro	77 474	300	30	0	0.5	0	0	0	0.5	200		0.5
Slovakia	49 035	130	13	30	0.2	0.10	0.02	0	0.2	129		0.3
Slovenia	20 253	80	8	1	0.2	0	0	0	0.2	70		0.2
Spain	505 990	60	6	1	0.1	0	0.003	0.02	0.1	36		0.1
Svalbard /Spitsbergen	62 160	10	1	0	0	0	0	0	0	0		0
Sweden	449 964	66 800	6 680	30 000	7.5	7	0.08	0	7.6	13 080		14.6
Switzerland	41 285	300	30	10	0.3	0.02	0.03	0	0.3	130		0.3
Ukraine	603 700	8 000	800	2 000	3.8	4	0.5	0	4.2	3 820		8.2
United Kingdom	244 110	17 500	1 800	2 200	5.1	4.4	0.08	0	5.2	4 304		9.6
Vatican City	44	0	0	0	0	0	0	0	0	0		0
EUROPE TOTAL	9 484 057	530 741	47 570	181 559	253.4	140.6	139	6	399	312 676		539.5

INTERNATIONAL MIRE CONSERVATION GROUP

ERNST MORITZ ARNDT UNIVERSITÄT GREIFSWALD

Wissen lockt. Seit 1456

WETLANDS INTERNATIONAL

2008

Peatland area 2008	Peat carbon stock 2008	Forested peatland area 2008	Emissions in 2008 from 2008 peatland drained for agriculture before 2008	Emissions in 2008 from 2008 peatland drained for forestry before 2008	Emissions in 2008 from 2008 peatland drained for peat extraction before 2008	Emissions in 2008 from 2008 peatland drained for other purposes before 2008	Emissions from peat from non-forested peatland 2008	Total degrading peatland area 2008	Emissions from peat extracted in 2008	**Total emissions from degrading peat 2008**	Total technically possible future emissions	**Country/area**
km^2	Mton C	km^2	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	Mton CO_2/a	km^2	not included	**Mton CO_2/a**	Mton CO_2	**EUROPE (ctd)**
2.7	0.3	1	0.003	0.002	0	0	0.003	2		**0.005**	0.875	Luxembourg
0	0	0	0	0	0	0	0	0		**0**	0	Malta
9.2	0.9	0	0.02	0	0	0	0.02	8		**0.02**	3	Moldova
0	0	0	0	0	0	0	0	0		**0**	0	Monaco
3 451	334	130	5.8	0	0	0	5.8	2 300		**5.8**	1 100	Netherlands
29 685	2 230	2 700	2.3	2.9	0.3	0	2.6	5 300		**5.4**	7 344	Norway
11 528	876	2 500	17.5	4.8	1.2	0	18.7	10 200		**23.5**	2 884	Poland
18.6	1.7	1	0.05	0	0.003	0	0.05	15		**0.05**	6	Portugal
962	95	10	1	0	0.03	0	1.0	420		**1.0**	313	Romania
199 410	19 948	50 000	87.5	40	11.4	0	98.9	62 600		**139**	65 707	Russia European part
0	0	0	0	0	0	0	0	0		**0**	0	San Marino
282	27.5	0	0.6	0	0	0	0.6	230		**0.6**	91	Serbia and Montenegro
118	11.6	60	0.2	0.08	0.02	0	0.2	110		**0.2**	38	Slovakia
74	7.1	1	0.2	0	0	0	0.2	67		**0.2**	24	Slovenia
57	5.4	1	0.1	0	0.005	0.02	0.1	37		**0.1**	18	Spain
10	1	0	0	0	0	0	0	0		**0**	3	Svalbard /Spitsbergen
65 623	5 000	30 000	7.5	7	0.08	0	7.6	13 080		**14.6**	16 470	Sweden
288	29	15	0.3	0.02	0.03	0	0.3	130		**0.3**	94	Switzerland
7 656	760	2 000	1.8	3	0.15	0	1.9	2 300		**4.9**	2 502	Ukraine
17 113	1 745	2 200	5.1	4.4	0.08	0	5.2	4 304		**9.6**	5 747	United Kingdom
0	0	0	0	0	0	0	0	0		**0**	0	Vatican City
504 608	**43 620**	**164 394**	**238**	**121**	**18**	**6**	**262**	**219 637**		**383.2**	**143 684**	**EUROPE TOTAL**

Appendix II

Joosten, H., and Clarke D. (2002) Wise use of mires and peatlands – Background and principles including a framework for decision-making., Internatonal Mire Conservaton Group and Internatonal Peat Society, Saarijärvi, Finland

Country (References)	Total peatland area	Peatland area currently used for agriculture	
	km²	(km²)	%
Belarus – (Bambalov)	23 967	9 631	40
Czech Rep.+ Slovakia (Lappalainen)	314	ca 100	ca 30
Denmark (Aaby)	1 420	ca 1 000	ca 70
Estonia (Orru)	10 091	ca 1 300	13
France (Lappalainen)	ca 1 100	ca 660	ca 60
Finland (Vasander 1996)	94 000	ca 2 000	2
Germany (Steffens)	14 200	ca 12 000	85
Great Britain (Burton)	17 549	720	4
Greece (Christianis)	986	ca 900	ca 90
Hungary (Toth1983)	1 000	975	98
Iceland (Virtanen)	10 000	ca 1 300	13
Ireland (Shier)	11 757	896	8
Latvia (Snore)	6 691	ca 1 000	15
Lithuania (Tamosaitis et al)	4 826	1 900	39
Netherlands (Joosten 1994)	2 350	2 000	85
Norway (Johansen)	23 700	1 905	8
Poland (Ilnicki et al.)	10 877	7 620	70
Russia (Kosov et al.)	568 000	70 400	12
Spain (Lappalainen)	383	23	6
Sweden (Fredriksson)	66 680	3 000	5
Switzerland (Küttel)	224	ca 160	ca 70
Ukraine (Żurek)	10 081	ca 5 000	ca 50
Total	880 196	124 490	14

Table 3/11 Peatland used for agriculture in some European countries. [112]

	km²
Finland	59,000
Russia	38,000
Sweden	14,100
Norway	4,200
Estonia	4,600
Latvia	5,000
Lithuania	5,900
Belarus	2,800
Poland	1,200
Germany	1,100
United Kingdom	6,000
Ireland	2,100
P.R. of China	700
USA	4,000
Canada	250
Total	148,950

Table 3/13 Estimates of terrestrial wetlands (incl. peatlands) drained for forestry [133]

Byrne K., Chojnicki B., Christensen T. (2004) EU peatlands: Current carbon stocks and trace gas fluxes, Carbo-Europe-GHG Concerted Action – Synthesis of the European Greenhouse Gas Budget Report 4/2004, University of Lund, Sweden

Table 12: *Peatland use (km²)*

Country	Joosten & Clarke (2002) Mire area (km2)	Joosten & Clarke (2002) Forestry area (km2)	Lappalainen (1996) Grass area (km2)	Lappalainen (1996) Crop area (km2)	Selin (1999) Peat cut area (km2)	Residual[a] (km²)
Albania	4	0	0	175	0	0
Andorra	2	0	0	3	0	0
Austria	100	0	0	0	0	100
Azores	1	0	0	0	0	0
Belarus	11412	2800	8667[b, e]	963[b, e]	120	-462
Belgium	3	0	144[b]	16[b]	0	-3
Bosnia and Herzegovina	10	0	0	140	0	0
Bulgaria	5	0	0	0	0	20
Croatia	1	0	0	0	0	0
Czech Republic	50	0	70	30	10	40
Denmark	50	0	1000	0	10	340
Estonia	3000	4600	1300	0	90	1010
Faroe Islands	25	0	0	0	0	5
Finland	32000	57200[c]	2000	0	550	-6550
France	100	0	0	660	10	730
FYRO Macedonia	5	0	0	25	0	0
Germany	390[d]	2189[d]	8559[d]	4724[d]	300	358
Greece	13	0	0[b]	71[b]	0	0
Hungary	30	0	50	25	0	225
Iceland	3500	0	1300	0	0	3200
Ireland	2100	2100	1240[b]	896[b]	900	4264
Italy	30	0	0	270	0	0
Latvia	4663	600	0	1000	20	317
Liechtenstein	1	0	0	0	0	0
Lithuania	750	590	397[b]	1000[b]	20	763
Luxembourg	1	0	0	0	0	2
Moldova	1	0	0	0	0	9
Netherlands	150	0	2000[b]	0[b]	0	200
Norway	22000	0	1900	4200	20	-120
Poland	2000	1270	7565	55	10	1600
Portugal	2	0	0	18	0	0
Romania	500	0	0	0	0	500
Russia European part	150000	14250	23760[b, e]	2640[b, e]	160	22190
Slovakia	13	0	7	3	0	3
Slovenia	10	0	0	0	0	90
Spain	10	0	0	23	0	27
Sweden	55000	14100	0	3000	110	-1210
Switzerland	200	0	80	20	0	0
Ukraine	5800	0	0	5000	30	-30
United Kingdom	1000	6000	310[b]	410[b]	40	9740
Yugoslavia	50	0	0	250	0	0
Total	**305202**	**105699**	**60349**	**25617**	**2400**	**37358**

[a] Residual area to match total peatland area. Small negative areas result from the uncertainty in areas under other land uses. For the calculation, negative residual areas were set zero. [b] Literature value gives total agricultural area only. Distribution between grassland and cropland use based on expert judgement. [c] Minkkinen *et al.* 2002, GCB 8: 785-799. [d] New GIS-based estimate from German Federal Agricultural Research Centre (Freibauer et al., in prep.). High area value may be based on different peatland definition assuming a more shallow depth of the peat layer. [e] Distribution between grassland and cropland very uncertain. Significant contribution to uncertainty in European CO_2 and N_2O estimates.

Rydin, J. and Jeglum, J. (2013) The biology of peatlands, 2.ed., Oxford University Press, Oxford, ISBN 978-0199603008

Modified excerpt of Table 11.1 in : The biology of peatlands, 2nd edition

			Part of peatlands (%) drained for:			
Country	**Peatland cover (km^2)**	**Proportion (%)**	**Agriculture**	**Forestry**	**Peat Mining**	**Total:**
Finland	79000	23	4	75	1	80
Sweden	66000	15	5	15	<1	20
Norway	30000	8	3	14	1	18
Belarus	22000	11	49	17	2	81
United Kingdom	17000	7	12	13	<1	25
Germany	17000	5	72	6	<1	78
Iceland	13000	13	52	<1	<1	53
Poland	12000	4	61	21	7	88
Estonia	9000	21	32	17	3	52
Ukraine	8000	1	9	20	1	30
Latvia	6000	10	14	11	6	31

Appendix III

Byrne K., Chojnicki B., Christensen T. (2004) EU peatlands: Current carbon stocks and trace gas fluxes, Carbo-Europe-GHG Concerted Action – Synthesis of the European Greenhouse Gas Budget Report 4/2004, University of Lund, Sweden

Table 6: *Emission factors based on measured fluxes from different bog and fen management types from European peatlands (median. Range and number of data sets n are given in brackets.).*

Managed - types of peatlands	Emission factor			GWP 100 (CO_2-C Equivalents kg ha^{-1} yr^{-1})
	CO_2 (t C ha^{-1} yr^{-1})	CH_4 (kg C ha^{-1} yr^{-1})	N_2O (kg N ha^{-1} yr^{-1})	
BOG (ombrotrophic)				
Forest (drained)	-0.19 [1,17,18,26] (-1.85 – 2.26, n=8)	11.15 [1,18,25,26,29] (-0.10 – 26.9, n=14)	0.04 [1,18,22,26] (0 – 1.10, n=7)	-105*
Drainage (for forest, peat cut)	1.10 [7,18,26,30] (-0.81 – 2.46, n=6)	20 [6,18,23,25,26,29] (0.02 – 78.9, n=9)	0.04 [6,18,23,26] (-0.01 – 0.60, n=16)	1253
Grassland	2.35 [10,11,21,31] (1.50 – 3.50, n=5)	2 [11,13] (2, n=2)	0.01 [11,13] (0 – 0.02, n=2)	2367
Arable	4.4 [11] (n=1)	0 [11] (n=1)	0 [11] (n=1)	4400
Peat cut**	1.75 [9,11,28,32] (0.63 – 13.3, n=11)	17.25 [28,32] (2.25 – 33.7, n=9)	0.4 [28] (n=1)	1930
Abandoned after harvested	2.35 [7,33] (0.41 – 4.43, n=4)	1.3 [6,33] (0.30 – 3.98, n=4)	1.09 [6,33] (0.5 – 1.69, n=2)	2501
Restoration	0.62 [7,33] (-0.65 – 1.92, n=5)	15 [6,33] (2.25 – 71, n=5)	0.02 [6,16] (-0.01 – 4.45, n=4)	736
FEN (minerotrophic)				
Forest (drained)	-0.2 [26,39] (-0.21 – 0.48, n=4)	-0.05 [1,2,3,14,15,20,26] (-1.8 – 44.5, n=13)	1.83 [1,3,14,15,20,21,22,26,30] (0.09 – 26.9, n=20)	42*
Drainage (for forest)	0.4 [18,23,26] (0.14 – 3.6, n=4)	1.0 [18,23,25,26,29] (0 – 11.3, n=7)	1.05 [18,23,26,30] (0.08 – 2.23, n=10)	547
Grassland	4.12 [19,24,27] (0.82 – 6.58, n=5)	0.4 [3,8,19,24,28,34] (-1.04 – 105, n=13)	5.05 [2,3,4,5,12,14,21,22,24,28,36,37] (0.30 – 38.8, n=60)	4794
Arable	4.09 [13,21,28] (1.09 –10.6, n=3)	-0.2 [8] (-0.20, n=2)	11.61 [5,12,14,21,30,38] (4.0 – 56.4, n=15)	5634
Restoration	-	12.4 [3] (6.5 – 18.3, n=2)	0.64 [16] (n=1)	179 (without CO_2-C)

Strack, M., ed. (2008) Peatlands and Climate Change, Internatonal Peat Society, Jyväskylä, Finland, pp 223

Table 7.1. *Greenhouse Gas Emissions from Restored and Non-restored (control) Sites of Different Peat Types, Regions and Restoration Types*

Country	precip/ temp (mm yr^{-1}/ °C)	Restoration type, vegetation	Time after restoration (yr)	NEE (CO_2) ($gCO_2\ m^{-2}\ yr^{-1}$)	CH_4 ($gCH_4\ m^{-2}\ yr^{-1}$)	N_2O ($gN_2O\ m^{-2}\ yr^{-1}$)	GWP[a] 100 yr (gCO_2-e $m^{-2}\ yr^{-1}$)	GWP[a] 500 yr (gCO_2-e $m^{-2}\ yr^{-1}$)	References
Cutover bogs (see section 7.2)									
Boreal									
Canada		Blocking of ditches, mulching with straw	3	1753[b]	1,3	0	1785	1763	Waddington *et al.*, 2002
		Peat cutting area, non-restored		871	0,02	0	871	871	
Sweden	800 / 6	Self regeneration, poorly drained, mean estimate	50	-460 to -37[c]			-460 to -37	-460 to -37	Lode, 2001
Finland	700 / 3.5	All: blocking ditches, additional water supply	10						Kivimäki *et al.*, in press
		Pure stands of *E. vaginatum*, or *C. lasiocarpa*		-80[d]			-80	-80	
		Mixed stands of *E. vaginatum* and *C. lasiocarpa*		-320[d]			-320	-320	
		Bare plots		150[d,e]			150	150	
Finland	700 / 3.5	All: self regeneration, poorly drained	52						Yli-Petäys *et al.*, 2007
		Wet: *S. pulcrum*		-143[d]	45		982	199	
		Dry: *S. papillosum*, *E. vaginatum*, *C. lasiocarpa*		40[d]	28		740	253	
Temperate									
the Netherlands	853 / 9	Damming of area	10	97	0	0	97	97	Nieveen *et al.*, 1998
Ireland	804 / 9.3	All: blocking of ditches, flooding	10						Wilson *et al.*, 2007
		Juncus, *Holcus* (drier places)		2281	0	0	2281	2281	
		Phalaris, *Typha* (wetter places)		1755	27.9	0	2453	1967	
		Eriophorum, *Carex* (wetter places)		1039	4.0	0	1140	1070	
		Bare soil		1019[e]	0	0	1019	1019	

Peatlands used for agriculture or forestry (see section 7.3)

Boreal bogs

Finland		Restored		-367[f]					Tolonen & Turunen, 1996
Sweden		natural		f	1,3 to 10,7	0,02	-329 to -94	-354 to -283	Nilsson et al., 2001; von Arnold et al., 2004
Sweden		Rewetted forest sites		-294	3	0,02	-213	-268	Nilsson & Nilsson, 2004

Boreal fens

Finland		Restored		-55[f]					Tolonen & Turunen, 1996
Sweden		natural		f	4 to 22,7	0,03	54 to 521	-20 to 122	Nilsson *et al.*, 2001; von Arnold et al., 2004
Sweden		Rewetted forest sites		-110	27	0,03	574	100	Nilsson & Nilsson, 2004

Temperate bogs

S Germany	1483 / 8.3	Drained and peat cutting (control 1)		1472	0,07	0,17	1525	1499	Drösler, 2005
		Drained (control 2)		864	1,9	0	911	878	
		Blocking ditches, damming	1-10	466	4,8	0	586	502	
		Natural		-264	25,9	0	383	-67	

Temperate fens

the Netherlands	790 / 9.8	Non rewetted control		2545[g]	0	1.47	2983	2770	Jacobs *et al.*, 2003
		Raising water table	31	1915[g]	0	0.97	2204	2063	
NE Germany	544/8.1	Flooded (0.2 to 1 m)	1	-917	0	0.22	-851	-883	Augustin, unpublished
		Low intensity pasture, raising water table	16	-2383	267	0	4300	-352	
NW Germany	697/8.7	Non rewetted control, unfertilized		1511[e]	-0.1	0.79	1744	1631	Meyer *et al.*, 2001
		Rewetting by ditches	4-5	1584[e]	-0.1	1.01	1882	1737	
		Flooding (0.1 m)	1-2	1833[e]	101	-0.07	4329	2588	

[a] GWP after Forster *et al.*, 2007. For 100 year time horizon GWP is 25 and 298 g CO_2-e for CH_4 and N_2O, respectively. For 500 year time horizon GWP is 7.6 and 153 g CO_2-e for CH_4 and N_2O, respectively.
[b] CO_2 emission from straw included
[c] net long-term peat accumulation
[d] values measured for growing season (June-Sept) were corrected by respiration in winter 70 g CO_2 m^{-2} yr^{-1} (Alm *et al.*, 1999b).
[e] bare soil
[f] values for all three gases were combined from Finnish and Swedish studies to calculate GWP
[g] carbon exportation by harvesting was included

Tabell 2. Litteraturverdier basert på studier i restaurertmyr.

					NEE – mg CO_2-C m^{-2} h^{-1}		mg CH_4-C m^{-2} h^{-1}		CO_2 – mg CO_2 ekv m^{-2} h^{-1}		CH_4 – mg CO_2 ekv m^{-2} h^{-1}		GWP – mg CO_2 ekv m^{-2} h^{-1}	
Forfattere	Myrtype	Lokalitet	Region	Land	Drenert	Restaurert	Drenert	Restaurert	Drenert	Restaurert	Drenert	Restaurert	Drenert	Restaurert
Beetz et al. 2013	Nedbørsmyr	Atlantisk høymyr	Temperert	Tyskland	47 (±26)	-2 (±23)	0 (±0)	0.1 (±0)	174 (±97)	-8 (±83)	1 (±1)	4 (±2)	174 (±98)	-4 (±85)
Cooper et al. 2014	Nedbørsmyr	Teppemyr	Temperert	Storbritannia			0.5	1			19	32	19	32
Aslan-Sungura et al. 2016	Grasmark	Landbruk	Temperert	Tyrkia	40 (±17)				146 (±61)					
Hatala et al. 2012	Grasmark	Sherman Island, CA	Temperert	USA	27 (±7)		0.3 (±0)		99 (±26)		11 (±3)		110 (±29)	
Hatala et al. 2012	Rismark	Sherman Island, CA	Temperert	USA		-21 (±11)		1 (±0)		-77 (±42)		19 (±7)		-58 (±49)
Hendriks et al. 2007	Grasmark	Horstermeer	Temperert	Netherland		-36 (±7)		4 (±2)		-130 (±24)		133 (±87)		3 (±111)
Herbst et al. 2013	Grasmark	Dyrket	Temperert	Danmark		-16 (±10)		1 (±0)		-59 (±38)		45 (±7)		-14 (±45)
Karki et al. 2016	Jordvannsmyr	Dyrket	Temperert	Danmark	0	-59	0	1		-217	1	21	1 (±0)	-196
Koebsch et al. 2013a	Torvuttak	Rodewiese - Torvuttak	Temperert	Tyskland		-0.5 (±0)		0.2 (±0)		-2 (±0)		6 (±5)		4 (±5)
Koebsch et al. 2013b	Torvuttak	Rodewiese - Torvuttak	Temperert	Tyskland				0.2 (±0)				6 (±5)		6 (±5)
Komulainen et al. 1998 & 1999*	Nedbørsmyr	Konilamminsuo mire & Viheriisenneva	Boreal	Finland	-1	-20 (±6)	1 (±0)	6 (±1)	-3	-74 (±22)	25 (±6)	208 (±51)	22 (±6)	134 (±73)
Komulainen et al. 1998 & 1999*	Jordvannsmyr	Konilamminsuo mire & Viheriisenneva	Boreal	Finland	-16	-58 (±16)	0 (±0)	2 (±1)	-57	-212 (±58)	4 (±5)	74 (±34)	-53 (±5)	-139 (±92)
Meijide et al. 2011	Rismark	Castellaro, Italy	Temperert	Italia		-42 (±1)		2 (±1)		-154 (±3)		93 (±26)		-61 (±29)
Nieveen et al. 1998	Grasmark	Fochtelooer	Temperert	Netherland	11									
Petrone et al. 2003	Torvuttak	Bois-des-bel	Temperert	Canada		128 (±29)				468				
Shurpali et al. 2009	Grasmark	Linnansuo, Finland	Boreal	Finland	-11 (±9)		0.0 (±0)		-42 (±32)					
Soini et al. 2010*	Jordvannsmyr		Boreal	Finland		-36 (±29)				-130 (±107)				
Strack & Zuback 2013	Torvuttak	Bois-des-bel	Temperert	Canada	59 (±39)	16 (±13)	0.1 (±0)	0.2 (±0)	216 (±143)	59 (±47)	3 (±8)	6 (±10)	219 (±151)	65 (±56)
Strack et al. 2014	Torvuttak	Ombrotrof nedbørsmyr	Boreal	Canada	105 (±72)	-22 (±28)	-0.1 (±0)	6 (±6)	385 (±264)	-79 (±101)	-3 (±2)	229 (±231)	382 (±266)	150 (±332)
Tuittila et al. 1999*	Torvuttak		Boreal	Finland	19 (±7)	-10 (±10)			71 (±27)	-35 (±38)				
Urbanová 2012*	Nedbørsmyr		Temperert	Tjekkia	-46 (±42)	-41 (±9)	1 (±1)	1 (±1)	-169 (±152)	-151 (±33)	24 (±26)	39 (±29)	-145 (±178)	-112 (±62)

					NEE – mg CO_2-C m^{-2} h^{-1}		mg CH_4-C m^{-2} h^{-1}		CO_2 – mg CO_2 ekv m^{-2} h^{-1}		CH_4 – mg CO_2 ekv m^{-2} h^{-1}		GWP – mg CO_2 ekv m^{-2} h^{-1}	
Forfattere	**Myrtype**	**Lokalitet**	**Region**	**Land**	**Drenert**	**Restaurert**	**Drenert**	**Restaurert**	**Drenert**	**Restaurert**	**Drenert**	**Restaurert**	**Drenert**	**Restaurert**
Urbanová 2012*	Jordvannsmyr		Temperert	Tjekkia	-29 (±27)		0.2 (±0)		-106 (±100)		8 (±8)		-98 (±108)	
Vanselow-Algan et al. 2015	Torvuttak	Nedbørsmyr	Temperert	Tyskland	83 (±8)	34 (±4)	0.0 (±0)	8 (±2)	306 (±28)	124 (±15)	1 (±2)	314 (±89)	307 (±30)	438 (±103)
Veenendaal et al. 2007	Grasmark	Oukoop	Temperert	Netherland	15 (±0)		1 (±0)		56 (±0)		50 (±8)		107 (±8)	
Waddington & Price 2000	Torvuttak		Temperert	Canada	41	19	0.1	0	152	71	5	1	157	72
Waddington et al. 2010*	Torvuttak	Bois-des-bel	Temperert	Canada	31 (±9)	-4 (±1)			112 (±32)	-16 (±5)				
Yli-Petäys et al. 2007	Torvuttak		Boreal	Finland		-30 (±24)		8 (±5)		-110 (±86)		285 (±202)		175 (±288)

*Verdier basert på sesongmessige estimater