

Universität  
Rostock



Traditio et Innovatio

**Navigating the transition to rewetted peatlands:  
Governance, economics and public knowledge**

**Kumulative Dissertation**

zur Erlangung des akademischen Grades

Doktor der Agrarwissenschaften (doctor agriculturae (Dr. agr.))

Fakultät für Agrar, Bau und Umwelt,

Lehrstuhl der Agrarökonomie,

Universität Rostock

vorgelegt von

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geboren am 12.10.1990 in Neubrandenburg

Rostock, 2026



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Jahr der Einreichung: 2025

Verteidigt am 9. Januar 2026



*“The difficulty lies not so much in developing new ideas as in escaping from old ones.”*

**John Maynard Keynes**

**NAVIGATING THE TRANSITION TO REWETTED PEATLANDS:  
GOVERNANCE, ECONOMICS AND PUBLIC KNOWLEDGE**



# TABLE OF CONTENTS

|                                                                                                                                       |      |
|---------------------------------------------------------------------------------------------------------------------------------------|------|
| Table of contents .....                                                                                                               | i    |
| List of abbreviations.....                                                                                                            | v    |
| List of figures .....                                                                                                                 | viii |
| List of tables .....                                                                                                                  | 9    |
| Chapter 1 .....                                                                                                                       | 1    |
| 1. Introduction .....                                                                                                                 | 3    |
| 1.1. Climate change and emissions reduction .....                                                                                     | 3    |
| 1.2. Multidimensionality of peatland rewetting .....                                                                                  | 4    |
| 1.3. Peatland Rewetting as a complex governance challenge.....                                                                        | 9    |
| 1.4. Peatland rewetting as a sustainable transition.....                                                                              | 10   |
| 1.5. Peatland rewetting as a task for society as a whole .....                                                                        | 11   |
| 2. Research gap.....                                                                                                                  | 11   |
| 3. Aim of the thesis.....                                                                                                             | 12   |
| 4. Specific research questions, methodological approaches and contribution .....                                                      | 12   |
| 4.1. Paper 1: How can peatland rewetting be understood and addressed as an exnovation governance problem? .....                       | 13   |
| 4.2. Paper 2: What lessons can be learned for peatland rewetting governance from the coal phase-out in Germany?.....                  | 13   |
| 4.3. Paper 3: What does the general public in Germany know about peatlands, and what are the patterns underlying this knowledge?..... | 14   |
| 4.4. Interlinking the three papers .....                                                                                              | 14   |
| 5. Structure of the dissertation .....                                                                                                | 15   |
| 6. References .....                                                                                                                   | 16   |
| Chapter 2 .....                                                                                                                       | 23   |
| Abstract.....                                                                                                                         | 25   |
| 1. Introduction: agriculture on drained peatlands.....                                                                                | 25   |

TABLE OF CONTENTS

- 2. Understanding peatland rewetting as exnovation..... 28
- 3. Research design..... 31
- 4. Structuring the phase-out of peatland drainage as exnovation governance ..... 32
  - 4.1. Discourse..... 32
  - 4.2. Policy instruments..... 33
  - 4.3. Agency ..... 35
  - 4.4. Justice..... 37
- 5. Political status quo: Peatland rewetting as an exnovation problem ..... 40
- 6. Discussion and conclusion ..... 42
- 7. References ..... 46
- Chapter 3 ..... 53
  - Abstract..... 55
  - 1. Introduction ..... 55
  - 2. Methods ..... 58
    - 2.1. Similarities and differences between coal and peatland drainage phase-out..... 58
    - 2.2. Rewetting pathways ..... 59
    - 2.3. Politically justified budget ..... 60
  - 3. Results ..... 63
    - 3.1 Comparison of coal phase-out and peatland drainage phase-out..... 63
    - 3.2. Rewetting pathways ..... 70
    - 3.3. Politically justified budget ..... 71
  - 4. Discussion..... 73
  - 5. Conclusion ..... 77
  - 6. Appendices ..... 79
    - A1..... 79
    - A2..... 80
    - A3..... 81
  - 7. References ..... 85

|                                                                                                                    |     |
|--------------------------------------------------------------------------------------------------------------------|-----|
| Chapter 4 .....                                                                                                    | 93  |
| Abstract.....                                                                                                      | 95  |
| 1. Introduction .....                                                                                              | 95  |
| 2. Methods .....                                                                                                   | 98  |
| 2.1. Study design.....                                                                                             | 98  |
| 2.2. Variables and measurement .....                                                                               | 98  |
| 2.3. Measured knowledge .....                                                                                      | 98  |
| 2.4. Subjective knowledge and self-assessment accuracy .....                                                       | 99  |
| 2.5. Correlation analysis .....                                                                                    | 99  |
| 2.6. R-Packages.....                                                                                               | 100 |
| 3. Results .....                                                                                                   | 100 |
| 3.1. The Dunning-Kruger effect applies to peatland knowledge .....                                                 | 100 |
| 3.2. Subjective and objective knowledge accuracy shows a gap along the determinants<br>.....                       | 103 |
| 4. Discussion and implications .....                                                                               | 105 |
| 5. References .....                                                                                                | 108 |
| 6. Appendices .....                                                                                                | 112 |
| A1: Variables and Measurements .....                                                                               | 112 |
| A2: Description of the sample .....                                                                                | 115 |
| A3: Correlation tables .....                                                                                       | 119 |
| A4: Questionnaire .....                                                                                            | 121 |
| Chapter 5 .....                                                                                                    | 139 |
| Synthesis and Outlook: Discussion, Contributions, and Future Research Directions.....                              | 139 |
| 1. Main results and interlinkage of the three papers as a contribution to answering the<br>research question ..... | 141 |
| 2. Discussion of the individual papers.....                                                                        | 142 |
| 2.1 Paper 1: Peatland rewetting as drainage exnovation – A transition governance<br>perspective .....              | 142 |

## TABLE OF CONTENTS

|                                                                                                                 |     |
|-----------------------------------------------------------------------------------------------------------------|-----|
| 2.2 Paper 2: Deriving a justified budget for peatland rewetting – Lessons from the coal phase-out .....         | 146 |
| 2.3 Paper 3: How Well are Peatlands Understood? Lessons from Measuring Subjective and Objective Knowledge ..... | 152 |
| 3. Contribution of the dissertation .....                                                                       | 162 |
| 3.1 Theoretical contribution .....                                                                              | 162 |
| 3.2 Applied contribution .....                                                                                  | 163 |
| 3.3 Methodical contribution .....                                                                               | 164 |
| 4. Implications for policy and practice .....                                                                   | 165 |
| 5. Limitation of the Dissertation: .....                                                                        | 166 |
| 6. Further Research .....                                                                                       | 167 |
| 7. References .....                                                                                             | 170 |
| 8. Appendices .....                                                                                             | 176 |
| A1: Variables and measurement of supplemental material .....                                                    | 176 |
| A2: Description of the supplemental material .....                                                              | 179 |
| Abstract .....                                                                                                  | 181 |
| Zusammenfassung .....                                                                                           | 183 |
| Danksagung .....                                                                                                | 185 |
| Eidesstattliche Erklärung .....                                                                                 | 187 |
| Authorship contribution .....                                                                                   | 189 |
| Curriculum Vitae .....                                                                                          | 190 |
| List of Publications .....                                                                                      | 192 |
| Conference Contributions .....                                                                                  | 193 |

## LIST OF ABBREVIATIONS

|                  |                                                                                                      |
|------------------|------------------------------------------------------------------------------------------------------|
| \$/person        | US dollars per person                                                                                |
| €                | Euro                                                                                                 |
| €/ha             | Euros per hectare                                                                                    |
| €/t              | Euros per ton                                                                                        |
| °C               | Degrees Celsius                                                                                      |
| %                | Percent                                                                                              |
| ANK              | Natural Climate Protection Action Programme (Germany)                                                |
| AOT              | Actively open-minded thinking                                                                        |
| approx.          | approximately                                                                                        |
| BbodSchG         | Federal Soil Protection Act (Germany)                                                                |
| BEHG             | German Fuel Emissions Trading Act<br>(Brennstoffemissionshandelsgesetz)                              |
| BfN              | Federal Agency for Nature Conservation (Germany)                                                     |
| BMEL             | Federal Ministry of Food and Agriculture (Germany)                                                   |
| BMU              | Federal Ministry for the Environment, Nature Conservation and<br>Nuclear Safety (Germany)            |
| BMUV             | Federal Ministry for the Environment, Nature Conservation, Nuclear<br>Safety and Consumer Protection |
| BMWi             | Federal Ministry for Economic Affairs and Energy                                                     |
| BMWK             | Federal Ministry for Economic Affairs and Climate Action                                             |
| ca.              | circa                                                                                                |
| CAP              | Common Agricultural Policy (European Union)                                                          |
| cf.              | confer – compare                                                                                     |
| CH <sub>4</sub>  | Methane                                                                                              |
| cm               | Centimetre                                                                                           |
| CO <sub>2</sub>  | Carbon dioxide                                                                                       |
| CO <sub>2e</sub> | Carbon dioxide equivalent (standardized measure for different<br>greenhouse gases)                   |
| Coal Commission  | Commission on Growth, Structural Change, and Employment<br>(Germany)                                 |

## LIST OF ABBREVIATIONS

|                  |                                                                                                 |
|------------------|-------------------------------------------------------------------------------------------------|
| COP27            | 27th UN Climate Change Conference of the Parties (2022)                                         |
| DBV              | German Farmers' Association (Deutscher Bauernverband)                                           |
| DF               | Discount Factor                                                                                 |
| e.g.             | exempli gratia – for example                                                                    |
| EU ETS           | European Emission Trading Scheme                                                                |
| EU               | European Union                                                                                  |
| Fig.             | Figure                                                                                          |
| GAEC             | Good Agricultural and Environmental Condition                                                   |
| GAK              | Joint Task for the Improvement of Agricultural Structure and Coastal Protection                 |
| GDR              | German Democratic Republic                                                                      |
| GDP              | Gross Domestic Product                                                                          |
| GDP per capita   | GDP divided by population                                                                       |
| GHG              | Greenhouse Gases                                                                                |
| GMC              | Greifswald Mire Centre                                                                          |
| ha               | Hectare (10,000 square meters)                                                                  |
| IPCC             | Intergovernmental Panel on Climate Change                                                       |
| KTBL             | Association for Technology and Structures in Agriculture (Germany)                              |
| KWSB             | Commission for Growth, Structural Change and Employment (often just called the Coal Commission) |
| LULUCF           | Land Use, Land-Use Change and Forestry                                                          |
| Mt               | Megaton – one million metric tons                                                               |
| n                | subset of the sample                                                                            |
| N                | total sample number                                                                             |
| N <sub>2</sub> O | Nitrous oxide                                                                                   |
| NDR              | North German Broadcasting (public broadcaster in Germany)                                       |
| p.a.             | Per annum – per year                                                                            |
| Peatland-PV      | combination of peatland rewetting and photovoltaic                                              |
| PESTL            | Political, Economic, Social, Technological, Legal, and Environmental analysis                   |
| PPP              | Purchasing Power Parity                                                                         |
| PV               | Present Value                                                                                   |

|        |                                                            |
|--------|------------------------------------------------------------|
| pWTP   | political Willingness to Pay                               |
| r      | Discount Rate                                              |
| RWI    | Rhine-Westphalia Institute for Economic Research (Germany) |
| SRU    | German Advisory Council on the Environment                 |
| t      | Metric ton (1,000 kilograms)                               |
| UBA    | German Environment Agency (Umweltbundesamt)                |
| UK     | United Kingdom                                             |
| UNEP   | United Nations Environment Programme                       |
| UNFCCC | United Nations Framework Convention on Climate Change      |
| WTP    | Willingness to Pay                                         |
| ZKL    | Future Commission for Agriculture (Germany)                |

## LIST OF FIGURES

**Chapter 1****Chapter 2****Chapter 3**

|           |                                                                                                                                                                                         |    |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 1: | Three pathways to rewet drained peatlands under agricultural use in Germany.....                                                                                                        | 59 |
| Figure 2: | Standardised contribution margin (€/ha) of agriculture on drained peatlands in Germany (district level) weighted as a share of peatland area of the total agriculturally used area..... | 66 |
| Figure 3: | Cumulative area gap and CO <sub>2</sub> emission gap between the current rate of rewetting and the rewetting pathways for agriculturally used peatlands in Germany in 2020-2029.....    | 71 |

**Chapter 4**

|              |                                                                    |     |
|--------------|--------------------------------------------------------------------|-----|
| Figure 1:    | Self-Assessment accuracy by aggregated knowledge levels.....       | 101 |
| Figure 2:    | Correlation between self-assessment accuracy and determinants..... | 102 |
| Figure 3:    | Correlation between knowledge and determinants.....                | 103 |
| Figure A2.1: | Distribution of correct answers.....                               | 116 |
| Figure A2.2: | Histogram of self-assessment accuracy.....                         | 118 |

**Chapter 5**

|           |                                                                                              |     |
|-----------|----------------------------------------------------------------------------------------------|-----|
| Figure 1: | Assessment of the comparison between the coal phase-out and peatland drainage phase-out..... | 154 |
| Figure 2: | Approval ratings for various statements on the rewetting of peatlands.....                   | 157 |
| Figure 3: | Assessment of media information about rewetting.....                                         | 160 |
| Figure 4: | Information about peatland on products.....                                                  | 160 |
| Figure 5: | Interest in topics in relation to peatlands.....                                             | 161 |

## LIST OF TABLES

### Chapter 1

### Chapter 2

|          |                                                                                                                                           |    |
|----------|-------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 1: | Governance dimensions of exnovation processes.....                                                                                        | 31 |
| Table 2: | Overview of four governance dimensions, the core aspects of an exnovation approach and current obstacles regarding peatland drainage..... | 39 |
| Table 3: | Measures of the peatland protection strategy within the framework of the four governance dimensions of exnovation.....                    | 40 |

### Chapter 3

|             |                                                                                                                                                         |    |
|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 1:    | Comparison of peatland area and emissions and GDP per capita in a selection of peatland rich countries. ....                                            | 57 |
| Table 2:    | Applicability of criteria used in the comparison of coal phase-out and peatland drainage phase-out in the six dimensions of the PESTLE framework. ....  | 64 |
| Table 3:    | CO <sub>2</sub> emissions per year resulting from the rewetting pathways for agriculturally used peatlands in Germany in the period 2020-2050.....      | 70 |
| Table 4:    | Overall CO <sub>2</sub> emission mitigation potential and politically justified budget for the peatland drainage phase-out in Germany. ....             | 72 |
| Table 5:    | Politically justified budget to rewet one ha peatland under agricultural use in Germany. ....                                                           | 72 |
| Table A1.1: | The necessary area of agricultural drained peatland in Germany that must be rewetted annually to achieve the CO <sub>2</sub> reductions in Table 3..... | 79 |
| Table A2.1: | CO <sub>2</sub> mitigation potential through the planned shutdown of lignite-fired power plants according to Annex II of the CPOA 2020.....             | 80 |
| Table A3.1: | Lignite: Calculations linked to Section 3.3.....                                                                                                        | 81 |
| Table A3.2: | Pathway A: Calculations linked to Section 3.3.....                                                                                                      | 82 |
| Table A3.3: | Pathway B: Calculations linked to Section 3.3.....                                                                                                      | 83 |
| Table A3.4: | Pathway C: Calculations linked to Section 3.3.....                                                                                                      | 84 |

### Chapter 4

|             |                                                   |     |
|-------------|---------------------------------------------------|-----|
| Table A1.1: | Description of the variables and measurement..... | 112 |
| Table A2.1: | Correlation between the categories.....           | 117 |
| Table A3.1: | Correlation values for Figure 2.....              | 119 |
| Table A3.2: | Correlation values for Figure 3.....              | 120 |

### Chapter 5

|             |                                                         |     |
|-------------|---------------------------------------------------------|-----|
| Table A1.1: | Variables and measurement of supplemental material..... | 176 |
|-------------|---------------------------------------------------------|-----|



CHAPTER 1  
INTRODUCTION



## 1. Introduction

### 1.1. Climate change and emissions reduction

Climate change is one of the biggest global challenges. To limit global warming, countries have agreed on international and national climate targets that require a reduction in greenhouse gas (GHG) emissions (IPCC, 2018). As part of the Paris Agreement (UNFCCC, 2015) and the National Climate Protection Act (BMU, 2021a), Germany has committed to significantly reduce its emissions compared to 1990 and be net GHG neutral by 2045.

Peatlands<sup>1</sup> have a dual role in reducing greenhouse gas emissions. While intact peatlands are carbon sinks due to the continuous formation of a peat layer and CO<sub>2</sub> absorption from the atmosphere, peatlands switch to a permanent and significant GHG emission source if the water level is lowered (Günther et al., 2020; Tiemeyer et al., 2020; Joosten et al., 2016). This so-called peatland drainage is mainly done to make the organic soil areas available for agriculture, forestry and peat extraction (UNEP, 2022; Succow and Joosten, 2001). To reduce or eliminate this permanent source of GHG emission, the water table needs to be raised back to a level near the surface - which is called peatland rewetting (Evans et al., 2021; Günther et al., 2020; Tiemeyer et al., 2020; Jurasinski et al., 2016). Degraded peatlands make a disproportionate contribution to the world's greenhouse gas emissions. While they cover only 0.3 % of the terrestrial surface of the Earth, they are responsible for 3-5 % of all anthropogenic CO<sub>2</sub> emissions (Joosten, 2016; Joosten et al., 2016). Without global peatland restoration measures and continued conversion in the tropics, CO<sub>2</sub> emissions from peatlands could exhaust up to 41 % of the remaining greenhouse gas budget required to limit global warming to 1.5-2°C by 2100 (Leifeld et al., 2019).

In Germany, around 95 % of organic soils are drained, resulting in GHG emissions in 2022 of approximately 53 million tons (Mt) of CO<sub>2</sub>-equivalent (CO<sub>2</sub>e), making up 7 % of total national GHG emissions (UBA, 2022). The water table of organic soils and their amount of annual GHG emissions are directly linked. In central Europe, including Germany, every 10 cm reduction in

---

<sup>1</sup> Within this doctoral thesis I follow UNEP (2022) by defining 'Peatlands' as "land with a naturally accumulated peat layer near the surface" (UNEP, 2022 p. 35), which "include both ecosystems that are actively accumulating peat and degraded peatlands that no longer accumulate but in contrast lose peat" (UNEP, 2022 p. 35).

Like the National Peatland Protection Strategy (BMUV, 2022, p. 72), this dissertation addresses all organic soils, i.e. both peatland soils according to the German soil science definition and other carbon-rich soils that are comparable to peatland soils in terms of their emission behaviour, such as 'Anmoore' and peatland succession soils. In this dissertation, the terms 'organic soils' and 'peatlands' are used equivalently.

the water table leads to an additional 5 tons (t) of CO<sub>2</sub>e per hectare (ha) annually (Joosten, 2024).

The federal forest inventory (BMEL, 2024) shows that due to the loss of living biomass as a result of climate change, the forest has become a GHG emission source since 2017. This in turn leads to a switch of the land use, land-use change, and forestry (LULUCF) sector in Germany from a net carbon sink to an overall GHG source (Öko-Institut, 2025; BMU, 2021b). At the same time calls the National Climate Protection Act for an improvement in the sink performance of the LULUCF sector to -25 (-35; -40) Mt of CO<sub>2</sub>e in 2030 (2040; 2045) (cf., BMU, 2021a). In order to achieve these sector-specific targets and enable overall GHG neutrality, peatland rewetting is necessary and requires timely action, as drained peatlands are a permanent source of GHG emissions (Günther et al., 2021; Leifeld et al., 2019).

GHG emissions from organic soils are primarily accounted for within the LULUCF sector, but in Germany, due to the large share of peatland drainage for agricultural use, these GHG emissions are directly linked to agricultural practices. In Germany, of the 1.8 million ha of drained organic soils, 1.3 million ha are used for agriculture, causing 43 Mt CO<sub>2</sub>e emissions (UBA, 2022). Therefore, rewetting peatlands under agricultural use is critical to increase the net carbon sink function of the LULUCF sector (BMU, 2021b). Despite the scientific evidence calling for the rapid rewetting of peatlands (e.g., UNEP, 2022; Tanneberger et al., 2021a; Günther et al., 2020), the pace of peatland rewetting has so far been rather slow (Barthelmes et al., 2021; Leifeld et al., 2019), and political efforts to shape change towards rewetting seem insufficient so far (UNEP, 2022; Grethe et al., 2021; Abel et al., 2019). Tanneberger et al. (2021a) proposed a rewetting pathway for Germany which aligns with international and national climate targets and assumes a full rewetting of all 1.3 million ha of agriculturally used organic soils by 2050.

## **1.2. Multidimensionality of peatland rewetting**

### *1.2.1 Agricultural use of drained peatlands*

In Germany, of the 1.3 million ha of drained organic soils under agricultural use, approximately 972,000 ha are classified as grassland and 335,000 ha as cropland, accounting for 80% of all drained peatlands (UBA, 2022). The GHG emissions differ depending on land use category and the resulting lowering of the water table, with arable land being drained usually more deeply than grassland and emitting 40.4 t of CO<sub>2</sub>e per ha per year, while grassland emits 31.7 t of CO<sub>2</sub>e per ha per year (Tiemeyer et al., 2020).

While agriculture makes only a marginal contribution to Germany's gross value added<sup>2</sup> (Statista, 2024), the regional concentration of peat soils means that efforts for large-scale rewetting could significantly impact local economies (Isermeyer et al., 2019). In fact, more than 80% of Germany's organic soils are concentrated in five federal states: Bavaria, Brandenburg, Mecklenburg-Western Pomerania, Lower Saxony, and Schleswig-Holstein (Thünen-Institut, 2023; Tegetmeyer et al., 2021). The peatland-rich areas differ significantly in terms of agricultural intensity and farm structure (Schaller, 2014; Röder and Osterburg, 2012). In north-eastern Germany, agricultural intensity is relatively low, with a substantial portion of the land used for suckler cow grazing. In contrast, southern and north-western Germany exhibit higher land-use intensity, with dairy farming as the predominant agricultural activity. Additionally, in north-western Germany, pig and poultry fattening farms further increase land-use pressure, as these operations rely on peatland areas both for fodder production and for manure application, in compliance with regulatory limits on nutrient spreading (Thünen Atlas, 2021; Röder and Osterburg, 2012).

Peatland drainage for agricultural use also has a significant cultural and historical dimension. In the past, it was also promoted by the state to create agricultural land and increase food production. These measures were part of land reclamation policies aimed at expanding farmland – like Prussia's King Friedrich II. in 1765 or the complex melioration in the GDR in the 1960s (Grethe et al., 2021; Zeitz, 2016c; Deickert and Piegsa, 2016). Over time, this has shaped regional economies, strengthened socio-economic dependencies and formed social narratives on drained peatlands (Hünnebeck-Wells, 2023; Tanneberger, 2023; Deickert and Piegsa, 2016; Schaller, 2014). However, after rewetting and establishing higher water tables, previous farming methods can no longer be applied, which presents significant social and economic challenges, particularly for farmers and the peatland-rich areas (Agora Agriculture, 2024; Wichmann et al., 2022; Nordt et al., 2022; Abel et al., 2019; Schaller, 2014).

### *1.2.2 Farm-specific costs*

Rewetting peatlands under agricultural use often involves substantial opportunity costs for farmers, particularly in high-yield dairy regions (Buschmann et al., 2020; Krimly et al., 2016; Drösler et al., 2013). In this case, the opportunity costs quantify the extent to which profits are

---

<sup>2</sup> According to Statista (2024), gross value added is the total value of goods and services produced in the production process minus the value of goods consumed in the production process at cost price (intermediate consumption - e.g. raw materials, intermediate products, trade goods, repair services, etc.).

reduced by, e.g. rewetting agricultural used areas compared to conventional production methods on drained peatlands and are therefore relevant for decision-making on a farm level (Schäfer et al., 2022; Wichmann et al., 2022). These costs are higher in the north-west and south than in the north-east of Germany due to the high regional added value from livestock production and the resulting land pressure (Wichmann et al., 2022; Röder and Grützmacher, 2012). Quantifying the economic effects of rewetting on individual farm level is difficult due to the great heterogeneity of the farms (e.g. farm structure, size, geographical location, land productivity and proportion of drained peatland in total farm area) (Wichmann et al., 2022; Schaller, 2014) but also due to a lack of data (Wichmann et al., 2022; Grethe et al., 2021). The reports by Nordt et al. (2022), Wichmann et al. (2022), and Schäfer et al. (2022) offer a comprehensive overview of the economic and individual economic factors, obstacles, and opportunities of peatland rewetting in Germany.

Studies on short-term, farm-specific opportunity costs due to losses in gross margins in Germany show varying results, depending on the applied methodology. Krimly et al. (2014) estimated opportunity costs for arable land between 330 €/ha and 1,148 €/ha and for grassland between 147 €/ha and 660 €/ha, while Schaller (2014) calculated values ranging from 160 €/ha to 3,877 €/ha for arable land and 851 €/ha to 1,706 €/ha for medium-intensive grassland. Alternative wet use options, such as paludiculture<sup>3</sup> or peatland-PV<sup>4</sup> (see section 1.2.3), could potentially offset these costs.

Assessing rewetting as GHG mitigation measures, abatement costs vary between 5 €/t and 92 €/t of CO<sub>2e</sub>, depending on the initial land use and region (Krimly et al., 2016; Schaller, 2014; Röder and Osterburg, 2012). Röder et al. (2015) show that to incentivise large-scale rewetting, mitigation payments of 50 €/t of CO<sub>2e</sub> would be sufficient in most regions, while in North-East, East and South Germany, 13 €/t could already be enough, whereas higher payments are necessary in North and North-West Germany. Buschmann et al. (2025) modelled the successive conversion of grassland use and confirmed the wide range of opportunity costs and the fact that, in the long term, complete rewetting is more effective and efficient than the wet use of grassland.

Regardless of the wide range of calculated costs and the degree of uncertainties, many studies advocate rewetting of agriculturally used peatlands as a cost- and area-efficient measure to offer

---

<sup>3</sup> Paludiculture is agriculture and forestry on wet or rewetted peatlands. It combines the usage of biomass growing or cultivated on peatlands with simultaneous peat formation or at least preservation of the peat body (e.g. Wichtman et al., 2016 p. 1).

<sup>4</sup> The combination of peatland rewetting and photovoltaic systems (peatland-PV) (cf., Seidel et al., 2024).

substantial leverage for climate action in the agricultural sector (cf., Buschmann et al., 2025; Niemi et al., 2024; Grethe et al., 2021; Hirschelmann et al., 2020). For the reason of completeness, it should also be mentioned with regard to the farm-specific costs that continuous drainage for agricultural use causes internal costs too, like the restoration of drainage infrastructure, soil subsidence and degradation (Zeitz, 2016a; 2016b).

Farmers will only consider rewetting if it is economically reasonable and combined with planning security (Wichmann et al., 2022). Without structural policy adjustments, current economic conditions do not provide sufficient financial incentives for large-scale peatland rewetting (Nordt et al., 2022).

### *1.2.3 Incentives for rewetting and peatland-friendly use*

As Hogan et al. (2024) note, establishing long-term payment mechanisms is crucial to provide effective incentives for farmers and landowners. Four main approaches can be distinguished: productive land use through paludiculture, carbon credit schemes, emerging biodiversity credit systems, and payments for ecosystem services. Paludiculture offers the possibility to reduce greenhouse gas emissions by raising the water table while maintaining agricultural productivity (cf. Wichmann, 2022; Wichmann et al., 2016). However, paludiculture is still in an early development stage and can be considered an emerging innovation or infant industry (Schäfer et al., 2022; Wichmann et al., 2022; Ziegler et al., 2021; Ziegler, 2020; Tanneberger et al., 2020). The combination of peatland rewetting and photovoltaic systems (peatland-PV) can mitigate land use conflicts, restore carbon storage functions, and reduce GHG emissions while contributing to energy security and climate protection (Seidel et al., 2024). Paludiculture and peatland-PV could enhance economic viability and social acceptance by providing farmers with financial incentives and diversifying land use benefits (Grethe et al., 2021). A lack of practical experience in paludiculture and peatland-PV and the required paradigm shift from land use on drained to wet peatland hinder stakeholder acceptance. Key aspects such as soil degradation from drainage and sustainable wetland-based management remain largely absent from professional education, vocational training, and advisory services (Wichmann et al., 2022; Schäfer et al., 2022; Abel et al., 2019). As instruments with an impact on utilisation and products, the support and funding of innovation and investment and the increase in demand are named. In connection with the latter point, this is often referred to as the ‘chicken and egg’-problem, as supply and demand must be created simultaneously (cf., Nordt et al., 2022b).

In order to expand peatland rewetting financing, mitigating investment risk through public sector support, robust standards and monitoring frameworks are also important to create planning security (Hogan et al., 2024; Schäfer et al., 2022; von Unger et al., 2019).

Schäfer et al. (2022) provide an overview of incentivised funding options to support rewetting and conversion to paludiculture, as well as existing funding systems in Germany. The following areas and operational instruments are mentioned here: Project and investment promotion from public and private funds; rewarding ecological services; reducing operating costs; and risk hedging.

### *1.2.4 Macro-economic perspective*

Rewetting peatlands also has broader macroeconomic implications as continued drainage-based use results in external costs related to infrastructure damage, biodiversity loss, and climate impacts (Joosten, 2024; Grethe et al., 2021; Page et al., 2020; Bonn et al., 2016). To illustrate the economic significance of rewetting agriculturally used peatland areas with regard to the emission reduction potential, Grethe et al. (2021) calculated an economic net benefit of 0.7 billion € per year for a CO<sub>2</sub> price of 60 €/t (CO<sub>2</sub> price according to BEHG for combustibles and fuels (BEHG, 2019)) and around 4.3 billion € for a CO<sub>2</sub> Price of 195 €/t (according to the UBA value factor based on the damage costs or social costs of carbon approach (UBA, 2020) – update note: in 2024, the UBA (2024) set a value factor of 300 €<sub>2024</sub> per t of CO<sub>2</sub>). Grethe et al. (2021) also highlight that the net benefit of rewetting is above the individual farm opportunity costs, even if one takes into account that successful farms can be above the average.

Willenbockel (2024) showed, based on a general equilibrium analysis, that an ambitious large-scale rewetting of peatlands under agricultural use is achievable at low macroeconomic costs. In summary, it can be said that the rewetting of agricultural peatlands to reduce emissions makes sense from a macroeconomic point of view, but so far, there are almost no incentives addressing the individual farm-level point of view.

### *1.2.5 Social and cultural aspects*

The historical drainage of peatlands is deeply embedded in agricultural traditions, shaping both landscapes and rural identities (Bruisch, 2022; Deickert and Piegsa, 2016). Draining peatlands is a cultural technique that was very innovative in earlier times in order to make non-usable land usable for agriculture, contributing to food security. In the past, drainage was also linked to a great deal of effort, which is why the drainage also had an identity-building effect (Zeititz, 2016a; 2016b). When discussing rewetting, it is important to consider and acknowledge the

efforts that have been made and to understand the historical narrative (cf., Tanneberger, 2023). This long-established practice has reinforced socio-economic dependencies, making rewetting a disruptive change. Many regions perceive drained peatlands as both a home-forming cultural landscape and an economic foundation, contributing to resistance against large-scale rewetting (Ziegler, 2020; Wichtmann et al., 2016).

Heindorf et al. (2024) point to a research gap concerning the relational values of peatlands. Their art-based study in northern Germany suggests that considering cultural and historical significance can reduce conflict and increase support for peatland restoration. A value-based approach that recognises local identities and encourages value shifts could support a more sustainable and inclusive transition.

It is also important to understand what society knows about the issue of peatland and peatland rewetting in order to be able to properly address and promote the issue of rewetting in societies. Just like the drainage of peatland, the rewetting of peatlands should not be a matter for individual landowners, but for society as a whole (Leopoldina, 2024; Grethe et al., 2021; Tanneberger et al., 2020)

### **1.3. Peatland Rewetting as a complex governance challenge**

Despite the adoption of a National Peatland Protection Strategy (BMUV, 2022), a Federal-State Target Agreement (BUND-LÄNDER, 2021), and the Natural Climate Protection Action Programme (ANK) (BMUV, 2023), a comprehensive long-term strategy with a concrete policy mix and timeline for peatland rewetting is still lacking. The set reduction target is to reduce peatland-related emissions by 5 Mt CO<sub>2e</sub> by 2030. Which in turn is not sufficient to achieve the climate protection goals, and moreover, no outlined time horizon for a complete phase-out of drainage-based land use has been communicated. Additionally, current strategies for rewetting rely on the principle of voluntariness, which is considered insufficient to meet binding climate targets (Wichmann et al., 2022; Grethe et al., 2021). Grethe et al. (2021) describe rewetting as a collective social responsibility. But on the farm level, does the acceptance decline as operational impacts increase (Krimly et al., 2016; Schaller, 2014). A lack of best practice examples and limited knowledge of alternative land uses also contribute to scepticism (Nordt et al., 2022; Abel et al., 2019). In addition, institutional complexity is a significant obstacle and can be characterised as a wicked problem (Meyer-Jürshof et al., 2025). To point out the multidimensionality and complexity of peatland rewetting, for instance, Meyer-Jürshof et al. (2025) and Lemke and Hirschelmann (2024) offer an overview and mapping of the layers, level of peatland protection, as well as legal framework conditions for rewetting and utilisation of

peatlands in Germany. For example, adjusting the water level or obtaining permission to block ditches is legally complex (Schlacke and Sauthoff, 2025a) and challenging also because water and soil associations prioritise drainage maintenance and historically follow the paradigm of drainage (Chen et al., 2023; Grethe et al., 2021). Schlacke and Sauthoff (2025b) provide an insight into the complex legal basis of peatland rewetting in Germany.

### **1.4. Peatland rewetting as a sustainable transition**

As introduced in the previous sections, drainage-based agriculture on peatlands is also reinforced by agricultural policies, economic structures, market incentives, technological infrastructures, history, and cultural narratives and forms a deeply rooted and stable system that creates path-dependent trajectories and lock-ins (Wichmann et al., 2022; Nordt et al., 2022; Schäfer et al., 2022; Grethe et al., 2021; Rosenbloom and Rinscheid, 2020; Heyen and Wolff, 2019; Schaller, 2014).

Based on this, rewetting of peatlands in line with climate targets can be linked to sustainable transition research. Sustainable transitions are goal-oriented and purposive in addressing environmental problems (cf., Ziegler, 2020; Geels, 2011). They involve deep structural changes in systems such as energy, transport, and agriculture to tackle challenges like climate change. To interlink sustainable transition and peatland rewetting, drainage-based agriculture on peatlands is characterised within this thesis as a socio-technical system to account for the interrelationship between technology, institutions, markets, policy frameworks, infrastructure, cultural meaning and social actors (Geels, 2005), which in turn generates path-dependent trajectories and lock-ins (Rosenbloom and Rinscheid, 2020; Heyen and Wolff, 2019). Within such socio-technical systems, the social and technological lock-ins are self-reinforcing because established technologies and practices have advantages over new entrants, leading to a path dependency that constrains future decisions and actions (Kotilainen et al., 2019; Arthur, 1989; David, 1985). A concept to describe the destabilisation of socio-technical systems is the exnovation governance approach (David and Gross, 2019; David, 2018, 2017; Heyen et al., 2017; Arnold et al., 2015).

Beyond that, sustainable transition research also highlights that research and governance often exhibit an innovation bias, prioritising technological advancements while neglecting the need for managed destabilisation (Davidson, 2019). Transferring this issue to peatland rewetting indicates that a shift away from drainage-based agriculture requires not only innovation and political support for alternatives such as paludiculture or peatland-PV but also an active phase-out of the drainage-based agricultural practices.

### **1.5. Peatland rewetting as a task for society as a whole**

Even though peatlands are concentrated in a few regions, rewetting and the resulting emission reduction benefit all citizens. Peatland rewetting can therefore also be seen as a task for society as a whole (Leopoldina, 2024; Grethe et al., 2021; Tanneberger et al., 2020). When public funds are to be used to support peatland rewetting as a socially acceptable transition - such as for compensation, rewards for climate services, or long-term support measures for the affected regions - this would also place a financial burden (cf., Wichmann et al., 2022; Grethe et al., 2021; Isermeyer et al., 2019). Thus, the pending political measures to govern peatland rewetting in line with climate targets are somehow also dependent on the support of society as a whole. Insufficient support can hinder policy adoption, undermine compliance, and reduce the overall effectiveness of climate actions (Lipari et al., 2024; Bergquist et al., 2022). Research has shown that knowledge among the population is crucial in shaping environmental concerns and support for climate policies (cf., Khatibi et al., 2021; e.g., Shi et al., 2016). Therefore, peatland rewetting as a sustainable transition also requires an understanding of the knowledge and perception of peatland rewetting throughout the population.

Previous studies on knowledge and perception of peatlands internationally or in Germany have mostly focused on specific groups such as visitors, farmers or experts (Hünnebeck-Wells et al., 2024; Flint and Jennings, 2022; Martino et al., 2022; Norris et al., 2021; Buschmann et al., 2020; Schaller et al., 2011). Recent research emphasises the importance of local communities, for example in Ireland (Flood et al., 2021, 2022), Germany (Heindorf et al., 2024) and Estonia (Päll and Pungas-Kohv, 2024). National surveys of the general population are rare and mostly limited to peatland-rich regions such as in Scotland or Finland (Byg et al., 2017; Tolvanen et al., 2012).

## **2. Research gap**

Originally introduced as an innovative process to increase agricultural productivity, peatland drainage has become deeply embedded in land use systems and is supported by long-standing policies, market structures, infrastructures and cultural narratives. As a result, it forms a highly stabilised socio-technical system characterised by strong path dependencies and institutional lock-ins.

However, the continued use of drainage-based agriculture is no longer compatible with current climate targets. While peatland rewetting is increasingly recognised as a critical strategy to reduce greenhouse gas emissions, there remains a significant knowledge gap on how to govern

this transition. In particular, the development of a governance roadmap for phasing out drainage-based land use in line with climate targets has not been sufficiently addressed to date. There is also a lack of comparisons with other transitions that have already been or currently are governed, which in turn limits the possibility of learning from successes and mistakes. Moreover, research on peatland rewetting governance has also paid little attention to the role of public knowledge. Understanding knowledge levels and their drivers is essential for designing effective policies and communication strategies that could increase societal support for the peatland rewetting transition process.

### **3. Aim of the thesis**

This thesis aims to:

1. Contribute to a better understanding of how peatland rewetting can be navigated as a multidimensional transition process which is both climate-target-consistent and socially acceptable.
2. Identify the need to conceptualise peatland rewetting as the active phase-out of peatland drainage.
3. Examine the various interrelated dimensions of peatland rewetting
4. Provide a governance-oriented framework for designing targeted instruments and timelines that facilitate a socially acceptable, large-scale transition towards rewetted peatlands.
5. Draw lessons from the German coal phase-out.
6. Address the public's knowledge as one driver for societal support for peatland rewetting.
7. Provide new insights to develop effective communication and policy strategies that will foster societal support and accelerate rewetting efforts.

### **4. Specific research questions, methodological approaches and contribution**

Based on the research gap and aim of this dissertation, I derived the overarching research question: ‘How can rewetting of agriculturally used peatlands in Germany be shaped as a sustainable transition process in line with climate targets?’

To answer this question, specific sub-questions are examined in three papers, which are part of this dissertation. In the following, I will give a short overview of the research sub-questions, methodological approaches and contribution, paper by paper.

#### **4.1. Paper 1: How can peatland rewetting be understood and addressed as an exnovation governance problem?**

Paper 1, presented in Chapter 2, examines peatland rewetting as a transition of a socio-technical system. It addresses the gap in research by integrating insights from sustainable transition research and peatland rewetting research, with a particular focus on exnovation.

Exnovation describes the purposive termination of existing (infra-)structures, technologies, products and practices of formerly innovative technologies and practices.

Four dimensions of exnovation governance are derived from theory (discourse, policy instruments, agency, and justice) and applied to evaluate the current German rewetting strategy. This approach expands the innovation-focused discourse (e.g. paludiculture) to include the importance of actively phasing out peatland drainage as an unsustainable technology and practice. The paper is, to the best of my knowledge, the first to spell out an exnovation governance approach for peatland rewetting.

#### **4.2. Paper 2: What lessons can be learned for peatland rewetting governance from the coal phase-out in Germany?**

Paper 2, presented in Chapter 3, examines the coal phase-out as a blueprint for peatland rewetting. The similarities and differences between the lignite and agricultural sectors are investigated using a PESTLE framework. In addition, a politically justified budget is derived for the socially acceptable phase-out of peatland drainage in line with the 1.5°C climate target. The budget derived from an exploratory calculation is based on the politically agreed budget for the coal phase-out and the emission reductions resulting from the phase-out pathway. In addition, the study analyses the discrepancy between the current pace of rewetting and rewetting pathways in line with climate targets.

The paper 2 contributes by establishing a conceptual and financial link between coal phase-out and peatland rewetting. Within the paper, three scenarios in line with the Paris Agreement are developed as rewetting pathways for drained peatlands under agricultural use in Germany. By calculating an emission- and area gap between the current and the Paris-Agreement required rewetting pace, the paper underlines the importance of rewetting timing and ambition. The paper introduces the politically justified budget, an approach that translates the preferences into peatland rewetting pathways based on a political willingness to pay for a socially acceptable emission reduction pathway, as demonstrated in the coal phase-out.

### **4.3. Paper 3: What does the general public in Germany know about peatlands, and what are the patterns underlying this knowledge?**

Paper 3, presented in Chapter 4, analyses the general public's knowledge of peatlands and rewetting. A nationally quota-representative survey (age, gender, education) was conducted (N=608). A correlation analysis serves as an exploratory approach to examine the driving determinants of objective and self-assessed knowledge, as well as over- or underconfidence in one's own knowledge. A quiz-based knowledge assessment, divided into three thematic categories, was developed within the study to measure objective knowledge. The paper aims to measure nationwide public knowledge about peatlands and rewetting and contribute to science communication by analysing public knowledge of peatland rewetting to get points of reference for communication strategies. The paper identifies possible target groups (e.g. individuals over- or underestimating their knowledge; individuals with low knowledge levels) and the underlying determinants.

This paper presents, to the best of my knowledge, the first nationwide survey of knowledge (self-assessed and objectively measured) on the subject area of peatland and rewetting of the general population in Germany.

### **4.4. Interlinking the three papers**

The three papers are linked as they focus on the governance of rewetting drained peatlands under agricultural use in Germany as a transition.

Due to time pressure to reduce emissions caused by peatland drainage for agricultural usage, governance is required to put pressure on the existing socio-technical regime to actively enforce the transition. **Paper 1** concentrates on the process of terminating the practice of peatland drainage, which is no longer consistent with the political objectives of emission reduction. The governance of peatland rewetting as a transition process is important and very complex due to the multidimensionality of the forces impacting this socio-technical regime. It could therefore be helpful to learn from other transition processes. In Germany, the coal phase-out is a prominent example of a governed transition process to phase-out an unsustainable practice and technology to reduce emissions; this comparison is discussed in **Paper 2**. The success of peatland rewetting governed as a sustainable transition also depends on the support and acceptance of the public. **Paper 3** focuses on the nationwide knowledge level about peatlands and peatland rewetting. Understanding public knowledge is important, as knowledge is one aspect to gain public acceptance, e.g. for the provision of funds and the implementation of measures, which is crucial in democratic nations. Without broad social support, resistance could delay or even hinder the implementation of rewetting measures.

## **5. Structure of the dissertation**

Chapter 1 introduces the research topic, outlines the research question, and explains the scientific relevance of the study. Chapters 2 to 4 present the three core research papers. Finally, Chapter 5 synthesises the main findings, discusses their political and scientific implications, and provides an outlook on future research.

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## CHAPTER 1

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CHAPTER 2

PEATLAND REWETTING AS DRAINAGE EXNOVATION –  
A TRANSITION GOVERNANCE PERSPECTIVE

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Published in *Land Use Policy* 143 (2024) 107191

<https://doi.org/10.1016/j.landusepol.2024.107191>



## Abstract

In the European Union, peatlands are largely drained for agriculture resulting in significant environmental damage and CO<sub>2</sub> emissions. Rewetting is seen as an effective tool to reduce CO<sub>2</sub> emissions, but drainage-based agricultural practices are locked-in. Instead of describing the scaling up of agriculture on wet peatlands, this paper examines the termination of drained peatlands use as an exnovation problem. Drawing on sustainability transitions research, we suggest exnovation as a conceptual perspective on the systemic changes towards sustainable agriculture. We propose a perspective on exnovation governance based on four dimensions: discourse, policy instruments, agency, and justice. We assess existing recommendations and government policy for peatland rewetting in Germany in terms of exnovation governance, and highlight strengths and omissions. The exnovation approach provides a new perspective for decision-makers, while peatland also offers a promising avenue for further research within this framework.

**Keywords:** Peatland; Rewetting; Exnovation; Governance; Phase-out; Sustainability Transitions

## 1. Introduction: agriculture on drained peatlands

The first Global Peatland Assessment launched at COP27 in Sharm El-Sheikh stressed that scientific evidence about drained peatlands as a significant greenhouse gas (GHG) emission source is accumulating worldwide (UNEP, 2022). About half of all peatlands are drained within the European Union (EU), making the EU the second-largest emitter from drained peatlands globally (Tanneberger et al., 2017; Tanneberger et al., 2021b).

Peatland ecosystems are formed when waterlogged soils prevent the complete decomposition of dead plant matter due to the lack of oxygen. Thus, a slowly growing (half a millimetre to a few millimetres per year) peat layer with a high carbon content is formed (Succow and Joosten, 2001; Timmermann et al., 2009). Globally, peatlands store more carbon than the global forest biomass, and intact peatlands are a long-term carbon sink (Joosten et al., 2016; Tanneberger et al., 2020). When these organic soils are drained, e.g. for agricultural use, the stored carbon is permanently released as CO<sub>2</sub> to the atmosphere until the whole peat layer is decomposed. The deeper the organic soil is drained, the higher the emissions (Tiemeyer et al., 2020). Therefore, stopping drainage – thus raising the water table and actively rewetting drained organic soils - can prevent high and permanent emissions of CO<sub>2</sub> (Günther et al., 2020; Joosten et al., 2016; Tiemeyer et al., 2020). However, with higher water tables, previous farming methods can no

longer be applied and must adapt to wet conditions (e.g. paludiculture) if the area should not be taken out of use (Tanneberger et al., 2020).

In Europe, peatlands are mainly drained for agricultural use (Succow and Joosten, 2001; UNEP, 2022) and until today, peatland drainage is a widespread agricultural practice despite significant environmental damage and GHG emissions, which governments have agreed to reduce to net-zero by the middle of this century (IPCC, 2023; Qiu et al., 2021; Tanneberger et al., 2022). For this purpose, rewetting, understood here as a phase-out of peatland drainage is a necessary and efficient measure to do so (Humpeöder et al., 2020; Leifeld et al., 2019; Leifeld and Menichetti, 2018; Strack et al., 2022; Tanneberger et al., 2021a). System-level change in agricultural production is therefore necessary (Humpeöder et al., 2020; Tanneberger et al., 2020), so that peatland drainage is no longer applied, amounting to a sustainability transition (David, 2017; Heyen et al., 2017). Phasing out the practice of peatland drainage implies deliberately destabilising a particular configuration of the agricultural system. This system consists of the material artefacts (such as technologies and infrastructure), actors and institutions (such as policies, norms or standards), as well as behaviours and knowledge that interact in the production of food and fibre (Geels, 2004; Markard et al., 2012). A host of studies has shown that such a deliberate destabilisation of particular, unsustainable system configurations is a central leverage point for change (Kanger et al., 2020; Koretsky et al., 2023; Rosenbloom and Rinscheid, 2020). Highlighting the difference to innovation-oriented approaches, such interventions have been discussed under the rubric of exnovation (David, 2017; Davidson, 2019; Heyen et al., 2017; Ziegler, 2023). With Heyen et al. (2017, p. 326) and Fossati et al. (2023), we understand exnovation as “the purposive termination of existing (infra)structures, technologies, products and practices” as well as the broader socio-technical configurations into which they are tied. Such a deliberate termination is necessary in socio-technical systems characterised by lock-in and incremental change (Heyen and Wolff, 2019; Rosenbloom and Rinscheid, 2020). Social and technological lock-ins are self-reinforcing because well-established technologies and practices carry advantages over new entrants, which leads to path dependency limiting future choices and actions (Arthur, 1989; David, 1985; Kotilainen et al., 2019). Driving mechanisms of such lock-ins include economics of scale, economics of scope, technological interrelatedness, network externalities, and learning effects (Arthur, 1989; David, 1985; Liebowitz and Margolis, 1995). Research on exnovation therefore draws attention to the deliberate termination of previously innovative, but nowadays outdated and unsustainable technologies, practices, or rules and their related infrastructure, to unlock system trajectories and create space for sustainable technologies and practices. As Davidson

(2019) notes, the failure to address climate change is not due to a lack of innovation, but rather a lack of exnovation.

Here, we therefore ask how peatland rewetting can be understood and addressed as an exnovation problem and how existing lock-ins of the socio-technical system can be overcome. To address these questions, we bring together conceptual approaches from sustainability transitions research (Köhler et al., 2019; Koretsky et al., 2023) with studies on peatland governance from agricultural economics and ecology (Joosten et al., 2016; Leifeld et al., 2019; Succow and Joosten, 2001; Tanneberger et al., 2020).

The deliberate destabilisation of systems such as agriculture has often been portrayed as the ‘flipside’ (Turnheim and Geels, 2012) of and being complementary to innovation-driven change, or even as parallel up- and downwards movements of old and new (Hebinck et al., 2022). This position is derived from the recognition that a mainly innovation-driven replacement of old technologies and practices by new ones, such as the diffusion of paludiculture techniques based on market demand for their products in the case of peatland drainage, is unlikely to proceed fast enough to reach agricultural climate targets (Grethe et al., 2021; Nordt et al., 2022). Such a development could result in too little and too slow rewetting and thus fail to meet the requirements of the Paris Agreement (United Nations, 2015). Yet, exnovation is not a quick or even simple fix, but a governance problem substantially different from innovation support (Koretsky et al., 2023). It highlights the challenges associated with opening up entrenched system trajectories and weakening stakeholders’ commitment to established technologies, practices and systems. We put forward a perspective on exnovation governance that addresses the policies and politics related to termination, thus drawing the definition of political objectives into the bracket (Frank and Schanz, 2022; Heyen et al., 2017). Ziegler (2020; 2023) and Ziegler et al. (2021) have discussed the cessation of peatland drainage as a case of exnovation. However, to our knowledge, no study has yet discussed the rewetting of peatland through the systematic application of an exnovation governance perspective. This article therefore makes two contributions to the literature: First, we introduce a new conceptual perspective to peatland governance scholarship by structuring the debate around the problem of exnovation. Second, we derive recommendations for policy- and decision-makers from this perspective.

In this contribution, we focus on the case of Germany. As a peatland- rich country Germany represents a crucial case for peatland governance. At 95 %, Germany holds a very high proportion of drained peatland relative to its total peatland area (Tanneberger et al., 2020), with drained peatlands contributing for 7 % of the nation’s overall GHG emissions (UBA, 2023).

Notably, agriculture stands out as the predominant land-use category on drained peatlands in Germany (Tiemeyer et al., 2020; UNEP, 2022). To keep this intervention concise, we restrict the analysis to the German national level, while highlighting links to EU and sub-federal levels of governance. Moreover, we limit our discussion to peatlands drained for agricultural use.

The rest of this paper is structured as follows. In Section 2, we discuss four governance dimensions and associated challenges from the literature on exnovation and related concepts. The research design is outlined in Section 3. In Section 4 we apply the four dimensions to peatland governance, drawing on literature and policy recommendations for peatland rewetting. Further, we examine the status quo of German peatland governance through the National Peatland Protection Strategy (BMUV, 2022) in terms of the four governance dimensions (Section 5). Finally, in Section 6 we discuss the significance and insights to understand peatland rewetting as an exnovation problem to advance and structure the debate in this rapidly growing field.

## **2. Understanding peatland rewetting as exnovation**

Since its advent, the study of sustainability transitions in agriculture and other sectors has largely focused on how the development and uptake of social or technological innovations brings about change. The concept of exnovation, on the other hand, draws attention to the deliberate termination of technologies, practices or rules and their related infrastructure that had previously been introduced as an innovation (David, 2017; Davidson, 2019; Heyen et al., 2017)<sup>5</sup>. For instance, peatland drainage was promoted as part of modernisation and expansion efforts in agriculture but is now increasingly problematised as the climate and environmental impacts of agricultural production dominate policy debates (Abel et al., 2019; Nordt et al., 2022; Qiu et al., 2021; Regina et al., 2016).

Yet, “exnovation is more than a mere reversal of innovation” (Fossati et al., 2023, p. 203). The concept directs attention to systemic processes of change that are associated with the termination of particular system elements. Consequently, exnovation is a relatively new type of “governance task” (Stegmaier, 2023, p. 97) that comes with new challenges. It requires active intervention to trigger or support processes of decline, even though the appropriateness of policy goals, instruments and governance arrangements is uncertain and politically contested

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<sup>5</sup> In sustainability transitions research, this issue is also discussed under related terms such as discontinuation (Stegmaier et al., 2014), decline (Rosenbloom and Rinscheid, 2020) or destabilisation (Frank and Schanz, 2022; van Oers et al., 2021). For an overview, see Koretsky et al. (2023).

(Fossati et al., 2023). Research on exnovation and decline has largely been developed to describe transitions in energy systems, but has already been productively applied to agri-food transitions (Kuokkanen et al., 2018). Using the term exnovation, we highlight the deliberate character of such interventions. Based on recent literature on socio-technical decline, we build on and synthesise earlier contributions on exnovation governance (David, 2015; Fossati et al., 2023; cf., Heyen et al., 2017) and structure this task into four dimensions and associated challenges. We label these dimensions as discourse, policy instruments, agency, and justice (Table 1).

First, exnovation requires discursively structuring the pertinent policy processes (Stegmaier et al., 2014). Establishing a clear problem perception and putting the issue on the agenda is necessary to initiate the policy process (Stegmaier et al., 2014). This relies on the formation of a stakeholder coalition to drive the termination process, and publicly promote the common goal. Such processes require a shared problem framing, including problem definitions, moral judgments and the suggestion of remedies (Entman, 1993). Moreover, determining and communicating the time horizon of the policy processes and the final exit from the technology or practice in question is central. Drawing on the example of the German nuclear phase-out, Heyen et al. (2017) argue that, while a clear end date is necessary, this time horizon should depend on the availability of substitutes and expected adjustment processes.

Second, policy instruments for terminating peatland drainage need to be designed and integrated into a coherent and consistent policy mix (Kern et al., 2019). These comprise, first, significant changes in the regulatory landscape, “such as structural reforms in legislation or significant new overarching laws” (Kivimaa and Kern, 2016, p. 209). For instance, Frank and Schanz (2022) refer to the shift towards Integrated Pest Management combined with quantitative reduction targets in European pesticide governance. A second policy instrument type are measures to reduce existing support for unsustainable agricultural technologies and practices (Kivimaa and Kern, 2016; Heyen et al., 2017). Such measures include not only the termination of ‘harmful’ direct and indirect subsidies but also the cessation of publicly funded research and training programmes (Kivimaa and Kern, 2016). As a third instrument type, Kivimaa and Kern (2016) name control policies, which comprise measures aiming to put pressure on the unsustainable agricultural system configuration. They can take the form of economic and market-based instruments, such as the European Emissions Trading System (Heyen et al., 2017). Other variants of control policies are regulatory bans and environmental standards. Moreover, exnovation policy mixes need to integrate individual policy instruments

in a mutually supportive way and require coherent implementation (Rogge and Reichardt, 2016).

Third, within the dimension agency, we address that exnovation governance requires a focus on involved actors and their interactions (Frank et al., 2020; Kivimaa et al., 2017; Kivimaa and Kern, 2016). To this end, knowledge, network, and capacity building are required. This can start with including pioneers and niche actors (e.g., NGOs, foundations, conservation agencies, planning and engineering offices working on rewetting projects) in advisory councils and institutions and further reorienting public research away from established practices. Kivimaa and Kern (2016) use the example of Dutch energy transition platforms. Second, administrative processes, structures and routines need to be adapted or newly established. For instance, Barbier (2017) describes the development of a new network organisation in the French process of reducing pesticide use by 50 %. Lastly, participatory processes with stakeholders and citizens can structure interactions and support the requisite societal acceptance for ambitious climate protection measures for exnovation governance. German examples with different composition and tasks are the Coal Commission, the Commission on the Future of Agriculture (ZKL, 2021), the Livestock Competence Network (Kompetenznetzwerk Nutztierhaltung, 2022) or citizen assemblies (Bosse et al., 2021; Kuntze and Fesenfeld, 2021).

The fourth dimension, which we label justice, touches on negotiations and just transitions more broadly. This comprises measures for socio- economic adjustment, as well as “socio-technical aftercare” (cf., Heyen et al., 2017; Stegmaier et al., 2014, p. 121), which should be considered at geographical scales (national/regional) and from the individual and collective perspectives of the most affected actors (Johnstone and Hielscher, 2017; Spencer et al., 2018). For instance, during the German lignite phase-out, compensation, support and adjustment programmes for particularly impacted regions had to be negotiated, and their requirements for infrastructural development and economic alternatives needed to be assessed (Leipprand and Flachslund, 2018). Moreover, professional groups impacted by the transition process need to be included. Such measures can include the reorientation of education programmes, as well as the reskilling of current professionals (Spencer et al., 2018). Table 1 summarises these four governance dimensions of exnovation.

**Table 1: Governance dimensions of exnovation processes**

| <b>Governance dimension</b> | <b>Description</b>                                                                                    |
|-----------------------------|-------------------------------------------------------------------------------------------------------|
| Discourse                   | Discursive structuring of the policy processes by an actor coalition driving the termination process. |
| Policy instruments          | Design and implementation of a policy mix for termination                                             |
| Agency                      | Building knowledge, networks and institutional capacities among actors in the socio-technical system  |
| Justice                     | Addressing socio-economic compensation and support for affected stakeholders and regions              |

**Source:** Own presentation.

### **3. Research design**

This paper aims to enrich the debate on peatland emissions reduction by showing how the concept of exnovation governance can serve to structure existing governance recommendations and highlight omissions and blind spots with a view to reducing greenhouse gas emissions from drained peatlands. To underscore the value of an exnovation perspective in this debate, we show how exnovation can be spelled out for peatland governance, and use the concept to make sense of policy recommendations from the literature and to examine the current German policy strategy.

Based on the conceptual literature on exnovation presented in the previous section, we structure existing policy recommendations along four dimensions of exnovation governance, with the aim of exemplifying intervention points derived from the exnovation concept for peatland rewetting. To this end, we have reviewed pertinent academic and grey literature on German peatland management for contained recommendations for managing peatlands with a view to GHG emissions reductions.

In order to assess the current German policy strategy on peatland rewetting, we analyse two key high-level policy documents, the National Peatland Protection Strategy (BMUV, 2022) and the Target Agreement between the Federal and Lander levels (BMEL and BMU, 2021). In a brief, exemplary application, we highlight governance approaches that are already covered, as well as gaps and shortcoming in the current German policy strategy as derived from the exnovation lens.

## 4. Structuring the phase-out of peatland drainage as exnovation governance

### 4.1. Discourse

First, the exnovation of peatland drainage requires discursively structuring the pertinent policy processes. The relevance of rewetting increasingly finds its way into climate change mitigation debates (BMUV, 2022; 2023a; UNEP, 2022). Resolving the conflict between nature conservation and climate protection requires reshaping problem framings and the definition of solutions (Grethe et al., 2021; Nordt et al., 2022). This necessitates taking into account the historical significance of peatland melioration, current sceptical attitudes towards rewetting projects as well as information deficits (Abel et al., 2019). Addressing current and future practices the historical value should be considered by attempts at exnovation governance.

Currently, a broad actor coalition to drive the exnovation process of peatland drainage is lacking. Conceivable is an alliance between organisations campaigning on the advantages of rewetted peatlands, the climate movement, frontrunner landowners and groups negatively affected by peatland drainage e.g. through damage to infrastructure and buildings, or increased infiltration of pollutants into groundwater. Offering financial resources and capacity building for (grassroots) organisations or campaigning initiatives could promote coalition building.

Moreover, Heyen et al. (2017) argue that determining and communicating the time horizon of the final exit from the technology or practice in question as well as the associated policy process is central for exnovation. Terminating peatland drainage translates to formulating a long-term strategy with a corresponding complete rewetting pathway. A debate about such pathways is already taking place (Nordt et al., 2022; Tanneberger et al., 2021a). Currently, the National Peatland Protection Strategy (BMUV, 2022) and the Federal-Länder-Target Agreement (BMEL and BMU, 2021) include a reduction target of 5 million tons of CO<sub>2</sub>e by 2030, which is to be achieved through voluntary measures. This target has been criticized for lacking ambition and following a principle of voluntarism (Boon et al., 2022; Grethe et al., 2021; Nordt et al., 2022). Nordt et al. (2022, pp. 18–23) provide an overview of proposed rewetting pathways for Germany, including more ambitious reduction targets. Tanneberger et al. (2021a) introduced a rewetting pathway in line with the Paris Agreement which stipulates rewetting all arable and grassland on organic soils by 2050. Centrally, the goal of an appropriate drainage phase-out in line with emission reduction targets needs to be firmly embedded in public discourse.

## 4.2. Policy instruments

Terminating the practice of peatland drainage requires the design and implementation of policy instruments embedded in a policy mix for this transition process (Kern et al., 2019).

As a first aspect of the policy mix, Kivimaa and Kern (2016) suggest control policies. Therefore, the adoption of national legislation could advance and complement the achievement of rewetting. To facilitate and push forward the process, laws concerning water, nature conservation, soil protection, agriculture as well as land consolidation and spatial reorganisation need to be adjusted (Grethe et al., 2021; Nordt et al., 2022; Wiegmann et al., 2022). Water management frameworks play a central role. This is acknowledged by the National Peatland Protection Strategy, although the level of ambition in its implementation remains unclear (BMUV, 2022).

Recent publications provide a wealth of specific suggestions: To ensure the preservation of the organic soils as provided in the German federal soil protection law (BBodSchG), water levels have to be specified for peatland management (Wichtmann et al., 2018). In order to protect drained peatlands as potential rewetting areas from settlement development, Schäfer and Yilmaz (2019) and Grethe et al. (2021) recommend an obligation under spatial planning law to create priority or reserved areas for peatland protection and conservation. Osterburg et al. (2018) suggest designating peatland areas for mandatory hydraulic engineering measures, e.g. such as water retention and water management. Peatland protection and conservation management could be anchored within good agricultural practice standards by defining peatland management and farming guidelines (Wichtmann et al., 2018). To facilitate and combine these numerous individual measures, from our perspective a peatland rewetting law similar to the coal phase-out law (Bundestag, 2020) could initiate and structure the complex legislative changes.

Control policies can put pressure on the agricultural system based on peatland drainage. Economic instruments could comprise embedding organic soils in emission certificate trading, a bonus-malus system or a peatland carbon credit scheme (Isermeyer et al., 2019; Tanneberger et al., 2020; Wichtmann et al., 2022). Wichtmann et al. (2022) identify following incentive-based financial instruments for Germany with which the existing obstacles to sustainable peatland use can be countered: Design of the Common Agricultural Policy; Establishment of a (initially national) emissions trading system for greenhouse gas emissions from peatlands; Bonus-malus system comprising climate protection bonus and CO<sub>2</sub> tax; Product labels and certificates; Regional trading system for heat certificates from paludiculture; Innovation and investment promotion; Peatland Climate Protection Fund. Following this analysis Schäfer et al. (2022)

discuss each of these instruments according to the criteria of scientific policy advice. The Greifswald Mire Centre (2020) also proposes establishing national peatland carbon credit schemes in the 16 EU member states with the highest peatland emissions. Grethe et al. (2021) advocate for an instrument mix building on supporting voluntary pioneers and increasingly applying the polluter-pays principle, to ensure that drainage ceases to make sense in microeconomic terms.

Moreover, to end drainage-based agriculture, existing support measures for unsustainable agricultural technologies and practices need to be reduced (Heyen et al., 2017; Kivimaa and Kern, 2016; Pe'er et al., 2019; Schmid et al., 2007). Currently, the design of the CAP with its support instruments at the national level contributes substantially to maintaining the status quo of drainage-based agricultural practices on organic soils (Ekardt et al., 2020; Rühls et al., 2016; Wiegmann et al., 2022). The current specification of the CAP's peatland protection standard, Good Agricultural and Environmental Condition (GAEC) 2 is not ambitious enough, since use as arable land with inverted tillage up to a depth of 30 cm is still permitted and an increase in water levels is not specifically addressed. Buschmann et al. (2020) argue that the GAEC 2 could be much more efficient and effective if it would rather address member states than single farmers. General CAP measures do not differentiate between implementation on mineral or organic soils (Röder et al., 2021; Wiegmann et al., 2022). Furthermore, a contractual climate or peatland protection analogous to contractual nature conservation (Wichmann et al., 2022) could set incentives and reduce microeconomic opportunity costs. The German Federal Agency for Nature Conservation (BfN) identifies payments that support economic activities on drained peatlands as environmentally harmful subsidies (BfN, 2019). By designing the CAP strategy plans at the national level, Germany also has the opportunity to harmonize agricultural support measures with an exnovation process.

Furthermore, public money for research and training should be aligned with the termination of peatland drainage (Kivimaa and Kern, 2016). Societal costs associated with drainage-based agriculture are very high. Therefore, rewetting and adapted farming practices (e.g. paludiculture) appear to be a socially cost-efficient way to manage peatland areas as the land can still be used economically and therefore reduce the opportunity costs of peatland rewetting (Abel et al., 2019; Naturkapital Deutschland, 2015; Nordt et al., 2022). The cultivation of energy crops (maize) on peatlands generates particularly high social costs through high emissions and counterproductive incentives (Naturkapital Deutschland, 2015). Regulatory bans are an appropriate measure for ending the use of crops grown on drained peat soils in biogas

plants, for instance by changing their classification as renewable energy (Naturkapital Deutschland, 2015).

We stress here that the literature contains many well-developed proposals. An exnovation perspective highlights the complexity of the policy mix and the need for long-term planning with sufficient time for stakeholders to adapt. Some recommendations have been adopted in the National Peatland Protection Strategy, but there is a lack of ambition to implement control policies (e.g. economic instruments), and no common approach is discernible so far. This contributes to a lack of trust in a long-term planning for a complete phase-out of peatland drainage. We note that to rethink the paradigm of voluntarism, a detailed legal examination of the encroachment on property associated with full rewetting could be beneficial, as similar reports were prepared for the coal phase-out (Agora Energiewende, 2017; Wissenschaftliche Dienst, 2018).

### **4.3. Agency**

As we deduced in Section 2, the transition literature highlights three fields of action within this dimension, starting with knowledge, network and capacity building; second, adapting administrative processes, structures and routines; and third, setting up a participatory stakeholder process.

Several measures have been suggested for knowledge, network and capacity building. To support pioneers, Wichmann et al. (2022) propose the establishment of paludiculture company networks and the strengthening of cooperation models. Establishing a business network for stakeholders who own or work on organic soils offers the opportunity to network, exchange ideas and advise each other. Such a network could also have an advisory function for planned funding programmes and the design of agricultural, environmental and climate protection measures. The foundation of machine rings or cooperative structures for the management of peatland areas can also reduce the individual financial burden of the farms. Such support approaches can be tested in cooperation between science and practice by setting up real-world laboratories (Wichmann et al., 2022).

Currently, planning and consultancy firms or offices offering knowledge about administrative processes, practical implementation, legal counselling and funding opportunities related to rewetting are lacking. Such agencies could be government-established; however, private actors are likely to establish themselves and thus a market for pertinent expertise if political pressure to rewet is sufficient. Approval procedures are complex, cost-intensive and lengthy and therefore cannot be realized by single stakeholders/ farms. This approval process requires the

involvement of project sponsors such as land companies and water-soil associations (Nordt et al., 2022).

Furthermore, strengthening administrative capacities can enhance transformative agency. This begins with orienting existing agencies towards the goal of peatland drainage exnovation. However, new agencies and posts should also be established for the management and administration of the peatlands acquired by the public sector. Following the national water strategy (BMUV, 2023b), water retention or peat-preserving water levels for organic soils should be a clear objective of the water-soil associations (Grethe et al., 2021; Wichmann et al., 2022). Water-soil associations and landscape conservation associations would also be suitable to coordinate the management and machine use of a hydrologically connected area across companies (Wichmann et al., 2022). Rewetting changes the hydrology of a larger area and thus has impacts beyond the scale of landscaping interventions. Thus, actors other than farmers must be involved in the process (see section “Justice” below).

To ensure coherent policy-making and implementation, Grethe et al. (2021) suggest an administrative coordination agency "Climate Agency Peatlands" as a higher federal authority. But also, the coordination and policy design from an institution at the level of federal states is important. Such an institution could for instance oversee the compilation and maintenance of datasets for efficient and sensible planning and implementation of rewetting measures. The Climate Protection Action Programme (BMUV, 2023a) and National Peatland Protection Strategy (BMUV, 2022) point towards such an institution: it stipulates the establishment of a committee for monitoring and coordination as well as a soil monitoring centre and the creation of the legal basis for recording and reporting emissions in the agricultural sector (BMUV, 2023a). However, we note that a detailed feasibility analysis with concrete proposals of how to integrate the needed tasks and institutions into existing structures and where to create new ones is currently missing.

Lastly, to guide the transition process participatory stakeholder approaches are required (Heyen et al., 2017). Such initiatives need to strike a balance between openness for co-creating change and implementing the pre-defined goal of peatland rewetting. The convening of a commission could be helpful in further structuring the policy process towards rewetting (Sommer et al., 2022). This format was recently used in Germany in the course of the coal phase-out by the coal commission (WSB, 2019), a general transformation of agriculture (ZKL, 2021) and a restructuring of animal husbandry (Kompetenznetzwerk Nutztierhaltung, 2022). To create a citizen assembly with a focus on peatland rewetting or as a predefined subtopic could be supportive. The participative character of such formats can support the legitimacy of such

processes of change, and policy design can be developed by experts, stakeholder and citizens participation. But as Bosse et al. (2021) mentioned, the recommendations of e.g. citizen assemblies are not binding but could at least help to policy to implement unpleasant but necessary measures. A prerequisite for the credibility of such a participatory process is to define the level of obligation to implement the recommendation as well as underline guidelines (e.g. emission reduction goals, phase-out dates) as given frameworks in advance. The development process of the National Peatland Protection Strategy (BMUV, 2022) has provided the possibility for comments to be submitted (BMU, 2021).

Concerning the peatland drainage phase-out, it would be appropriate to develop alternatives and visions in affected areas to offer information to farmers and residents, to take concerns and fears seriously and to show perspectives. Rewetting projects can lead to conflicts on various levels. Large melioration projects are often seen as part of a cultural heritage, and a historical achievement of having made drained areas arable. The targeted transition therefore requires an understanding of the history and the role of food production for farmer identities, agricultural traditions as well as farmers' fears of material losses.

#### **4.4. Justice**

The decline of an established socio-technical system such as drainage-based agriculture strongly affects a large range of stakeholders. As these impacts are likely to be geographically and socio-economically highly uneven, addressing necessary adjustments early is a requirement of just transition processes (van Oers et al., 2021).

Peatland areas are mainly concentrated in five states in Germany (Nordt et al., 2022). These regions are therefore disproportionately affected by the rewetting of drained peatland areas. Thus, Grethe et al. (2021) argue that these regions should be particularly supported in the associated structural change, which requires a long-term strategy. Isermeyer et al. (2019) mention national and interregional financial compensations since the effects of rewetting on social structures and the regional economy are concentrated in a few regions, whereas climate change mitigation benefits all citizens. A national peatland protection fund (WBAE, 2016) or existing federal payment mechanisms such as the joint task 'improvement of the agrarian structure and the coastal protection' (GAK) (Osterburg et al., 2018) could also be used as a burden-sharing mechanism (Grethe et al., 2021). Wichmann et al. (2022) suggest that an established fund could also serve to offset claims for damages from neighbouring areas. Otherwise, there could be a risk that rewetting projects cannot be carried out or will be carried out late.

Addressing peatland rewetting as an exnovation process emphasises the socio-technical adjustments which are necessary to mitigate impacts on affected producers and regions. Such adjustments comprise assurances of support and financing for transitions in infrastructure, compensation, reskilling and changing professional training, and require adequate co-determination of affected groups in the process. The implementation of rules for compensation, support and adjustment programmes could support the acceptance and decision on the business and individual levels. Including professional groups impacted by the transition process could help to meet the emerging demand as well as promotes a change in thinking and self-image of the professional group of for example farmers, hydrologists and agricultural advisors.

Moreover, rewetting is likely to adversely affect a farm's economy (Röder and Grützmacher, 2012). Thus, Schaller (2014) notes that the income losses must be compensated by compensatory payments to achieve participation in rewetting measures. Differences in economic impacts (e.g. between tenants and owners) and related dependencies must be considered when designing compensation payments and implementing rewetting measures.

In the future, there will be an increasing need for specialists in planning offices, administration, advisory networks, and practical implementation who are trained in peatland rewetting. It is therefore necessary that such skills and knowledge be integrated into education and professional training to ensure a viable future for affected professional groups. Currently, the climate-friendly use of peatlands or rewetting is only part of a few agricultural science courses (Abel et al., 2019). The management and care of areas with high water levels should also be part of agricultural training to cover the developing need for specialists and establish a new job profile for (peatland) climate managers. Thus, provided ecosystem services must be rewarded and valued. The task of agricultural management should be actively expanded to include climate protection (Wichmann et al., 2022). Schaller (2014) highlights that self-image, values and professional identity are important considerations when defining compensation options. Existing advisory networks and structures can be used to provide information about the possibilities and implementation of climate-friendly peatland management/care and to be able to provide company-specific advice.

In general, a long-term and cross-sectoral strategy and extensive financial resources are required to shape a socially acceptable transition. Sommer et al. (2022) examine the similarities and differences between the decision to phase-out lignite in Germany and the rewetting of drained peatlands. This comparison illustrates that for a socially acceptable pathway for extensive peatland rewetting a budget of ca. 13 billion € could be politically justified. For a targeted termination of peatland drainage as a just transition, the four dimensions of the

exnovation processes spelt out above need to be jointly addressed in a coherent policy process.

Table 2 summarises our arguments.

**Table 2: Overview of four governance dimensions, the core aspects of an exnovation approach and current obstacles regarding peatland drainage**

| <b>Governance dimension</b> | <b>Core aspects of an exnovation approach</b>                                                                                                                                                                                                                                                                                                                                                                                                                | <b>Obstacles</b>                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Discourse                   | <ul style="list-style-type: none"> <li>- Setting the final exit date</li> <li>- Defining the policy process</li> <li>- Building stakeholder coalition</li> <li>- Publicly promoting the common goal</li> <li>- Creating shared problem framing, definition, judgment, suggest remedies</li> </ul>                                                                                                                                                            | <ul style="list-style-type: none"> <li>- Tension between nature conservation and climate protection</li> <li>- Historical significance of the melioration of peatlands</li> <li>- Key actors oppose/doubt drainage phase-out</li> <li>- Current policy goals lack ambition</li> <li>- Voluntary participation approach</li> </ul>                                                                                                                          |
| Policy Instruments          | <ul style="list-style-type: none"> <li>- Financial Support of rewetting/ phase-out drainage</li> <li>- Supporting Innovation/ Niche Actors</li> <li>- Defining Regulatory bands and environmental standards</li> <li>- Economic and market-based instruments</li> <li>- Adjust CAP and funding regulations</li> <li>- Termination of indirect and direct subsidies</li> <li>- Publicly funded research</li> <li>- Adjust the regulatory landscape</li> </ul> | <ul style="list-style-type: none"> <li>- CAP and national agricultural support instruments maintain drainage-based agricultural practices</li> <li>- CAP GAEC 2 allows continued drainage</li> <li>- Current funding guidelines direct long-term investments in peatland drainage</li> <li>- Mandatory change in management practices encroaches on private property</li> <li>- No economic incentives to stop agriculture on drained peatlands</li> </ul> |
| Agency                      | <ul style="list-style-type: none"> <li>- Participatory Processes</li> <li>- Administrative: adjust and implement administrative processes; coordination between federal state and Länder</li> <li>- Knowledge, Network and Capacity building: Data collection; Sharing of knowledge; Including pioneers and niche actors</li> </ul>                                                                                                                          | <ul style="list-style-type: none"> <li>- Cultural heritage and societal anchoring</li> <li>- Farmer identities linked to food production</li> <li>- Fears of material losses</li> <li>- Administrative structures designed for drainage</li> <li>- Drainage anchored in professional training</li> <li>- Poor data availability</li> </ul>                                                                                                                 |
| Justice                     | <ul style="list-style-type: none"> <li>- Socio-economic adjustments on an individual and collective basis</li> <li>- Support for affected regions in structural change</li> <li>- Involve affected professional groups and stakeholders</li> <li>- Reskilling and reorientation of education</li> <li>- Rules for compensation, support and adjustment programmes</li> <li>- Socio-technical aftercare</li> </ul>                                            | <ul style="list-style-type: none"> <li>- Affected regions and financial burden unevenly distributed</li> <li>- Climate-friendly use of peatlands or rewetting is not widely part of professional education and university courses</li> <li>- Economic losses from rewetting without compensation</li> </ul>                                                                                                                                                |

Source: Own work.

### 5. Political status quo: Peatland rewetting as an exnovation problem

Building on the insights from the previous sections, we examine the National Peatland Protection Strategy (BMUV, 2022) and the Target Agreement between the Federal and Lander levels (BMEL and BMU, 2021) in terms of the four governance dimensions. These high-level policy strategies serve as a proxy of the status quo regarding ambition, policy design and governance process. On this basis, we elaborate missing aspects regarding an exnovation approach.

**Table 3: Measures of the peatland protection strategy within the framework of the four governance dimensions of exnovation**

| <b>Governance dimension</b> | <b>Measures supporting exnovation: Mentioned</b>                                                                                                                                                                                                                                                                                                                                                                                                                        | <b>Measures supporting exnovation: <u>Not</u> mentioned</b>                                                                                                                                                                                                                                                                                                                                                      |
|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Discourse                   | <ul style="list-style-type: none"> <li>- Based on the 2025 progress report: define a phase-out pathway of peatland drainage; examine whether the strategic approach has proved successful or whether it is necessary to realign and strengthen the legal framework.</li> <li>- Publicly promoting a strategy and goal</li> <li>- Shared problem framing</li> </ul>                                                                                                      | <ul style="list-style-type: none"> <li>- Time horizon for full rewetting/ rewetting pathway in line with emission reduction targets</li> <li>- Formation of a coalition to drive the transition</li> <li>- Reorienting problem framing of rewetting from voluntary project to socio-technical transition</li> <li>- Supporting grassroots organisations or campaigning initiatives (e.g. financially)</li> </ul> |
| Policy Instruments          | <ul style="list-style-type: none"> <li>- Financial support for rewetting</li> <li>- Termination of direct and indirect ‘harmful’ subsidies</li> <li>- Adjust CAP</li> <li>- Publicly funded research and training</li> <li>- Reform in legislation</li> <li>- Guidelines and regulations in water table and management</li> </ul>                                                                                                                                       | <ul style="list-style-type: none"> <li>- Significant overarching law addressing rewetting</li> <li>- Detailed legal examination of encroachment on property</li> <li>- Control policies like economic instruments, regulatory bans and environmental standards</li> </ul>                                                                                                                                        |
| Agency                      | <ul style="list-style-type: none"> <li>- Guidelines for selected decisions and process</li> <li>- Reorientation of relevant positions</li> <li>- Intended to establish new positions and committees</li> <li>- Define new tasks</li> <li>- Cooperation between federal and länder levels</li> <li>- Cooperation and Network building</li> <li>- Data collection and access</li> <li>- Knowledge sharing</li> <li>- Including pioneers and niche stakeholders</li> </ul> | <ul style="list-style-type: none"> <li>- Implementation of participatory policy process with stakeholders</li> <li>- Consistent and profound restructuring of structures and processes</li> </ul>                                                                                                                                                                                                                |

|         |                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|---------|----------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Justice | <ul style="list-style-type: none"> <li>- Reorientation of education programs</li> <li>- Reskilling of current professionals</li> </ul> | <ul style="list-style-type: none"> <li>- Defined measures and guidelines for socio- economic adjustment on an individual and collective basis</li> <li>- Rules for compensation, support and adjustment programmes</li> <li>- Support for affected regions undergoing structural change due to rewetting</li> <li>- Involve affected professional groups and stakeholders in scenario-building, planning and implementation</li> <li>- Measures for socio-technical aftercare</li> </ul> |
|---------|----------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

**Source:** Own summary of relevant measures of the National Peatland Protection Strategy (BMUV, 2022) and the Federal-Länder-Target Agreement (BMEL and BMU, 2021).

**Note:** We summarized the listed measures from the following fields of action: Protection and restoration of peatlands; Agricultural use; Water management framework conditions; Research and education; Legal framework and support measures; Public relations, data and monitoring and Reporting obligations and evaluation. We excluded the category: Land owned by the federal government and the federal government's role model effect because it targets a special case of property – even though the measures are more ambitious than those for rewetting in general. The list is supplemented by additional measures from the Federal-state target agreement. Within the last column, we list the ‘Measures supporting exnovation’ from Table 2 which are not mentioned in the National Peatland Protection Strategy and the Federal-state target agreement.

As we show in Table 3, some relevant aspects for all the dimensions are addressed within the current adapted political strategy. However, central here are questions of liability and specification of the wording used. Frequently used phrases describing the measures are unspecific in terms of implementation and timing. Therefore, implementation and execution and thus the effectiveness of individual measures cannot be precisely evaluated at this point.

Within the discourse dimension, what is centrally missing is a clearly defined termination date with a corresponding rewetting pathway compatible with the Paris Agreement. In the policy dimension, the main aspects are addressed, but envisioned approaches remain within the paradigm of voluntariness. Further, control policies (cf., Kivimaa and Kern, 2016) are initially excluded as instruments to put economic pressure on peatland drainage. The strategy shows that the complexity of and necessity to harmonise existing guidelines and regulations in the interests of rewetting is understood, but the strategy is mostly limited to statements that change is advocated and an audit is carried out. In the agency dimension, our analysis reveals that attempts are made to restructure and implement processes for peatland rewetting; but to what extent new positions, processes and capacities in the administration will be established is unclear. Overall, the political process could be facilitated, given a higher profile, and possibly sped up, by a participatory process or a commission. Last but not least, regarding the justice dimension, our analysis shows that the current rewetting strategy lacks a roadmap for a socio-economic adjustment and socio-technical aftercare to build towards a just transition process.

## 6. Discussion and conclusion

We contend that the rewetting of peatlands should be understood as the deliberate termination of the practice of drainage. Implementing this goal would be more than an innovative approach for reducing agricultural GHG emissions: due to the systemic nature of the changes, it would instead amount to an important aspect of a sustainability transition within the agricultural sector. Rewetting should therefore be addressed as an exnovation process, with the aim to open up locked-in trajectories of this socio-technical system through deliberate termination with governmental pressure, and to weaken the commitment of stakeholders to established system configuration. An exnovation approach directs attention to the systemic nature of change that reaching agricultural climate targets requires.

Through the interdisciplinary consideration of the challenges and necessities of peatland rewetting presented here, we aim to contribute to an understanding of key characteristics of this governance problem. We contend that our approach thereby serves as a useful heuristic to structure existing governance recommendations, and thus can be used to outline a pertinent policy mix. We argue that an exnovation perspective can offer a theoretically founded, systematic underpinning for existing policy suggestions aiming to support a transition within the land-use sector. The framework points to dimensions of such processes which have not yet been sufficiently addressed. It also enables a comparison of different processes of deliberate decline. Examples discussed as exnovation are the transitions in mobility (Wetzchewald, 2023) and energy (David, 2017). There is a growing field studying transitions within the agriculture and agri-food system (Klerkx and Begemann, 2020). Like Graaf et al. (2021) analysed the exnovation policies for urban mobility transition in eight cities around the globe, such a comparison for peatland-rich countries could create added value. With this framework, we underline that rewetting peatland areas in line with the Paris Agreement amounts to a profound socio-technical transition which needs a multi-level governmental strategy and political guidance. Understanding peatland rewetting as an exnovation process offers “intuitive terms and [...] a fruitful umbrella concept for a much deeper scientific discourse on dynamics, challenges and (successful) governance approaches in such processes” (Heyen et al., 2017, p. 327). To advance this transition process, a policy approach and governance structures rejecting further drainage and supportive of rewetting should be encouraged and partly even need to be newly created.

Conceptually, an additional advantage of an exnovation perspective is that it draws attention to termination as part of a governance strategy for a transformative, systemic change of agricultural production in the face of climate change and biodiversity loss. While we have

focused on the added value of an explicit exnovation governance for analytical clarity, terminating peatland drainage and supporting innovations that partially replace agriculture on drained soils are clearly connected. Specifically, a socio-technical transition away from agriculture on drained soils encompasses innovation pathways, e.g. one revolving around paludiculture, suitable photovoltaic systems, value chains for paludiculture products and payments for ecosystem services on rewetted peatlands. A strong innovation pathway of this kind could significantly support the acceptance and effectiveness of exnovation governance, as governance supporting these innovations could directly reduce farmers' opportunity costs and increase stakeholder as well as public confidence in the transition (Abel et al., 2019; Buschmann et al., 2020; Grethe et al., 2021; Wichmann et al., 2022). When considering the nexus between innovation and exnovation it is important to note that, while the support of innovation has near unanimous support, exnovation governance is terminologically unknown and politically unpopular (Turnheim, 2023). Furthermore, Ziegler (2020) views the exnovation approach not only as the flip-side of an innovation like paludiculture, but also includes the option to take agricultural land out of use after rewetting. Therefore, exnovation governance can also strengthen and complement nature and landscape conservation by allowing rewetting without an ensuing productive use.

Ziegler (2020) mentions further the window of opportunity which occurred in the course of the German reunification, in which Michael Succow and other nature conservation advocates seized the opportunity to support nature conservation and rewetting. With respect to politically set targets to limit global change and the resulting time pressure: The possibility of a window of opportunity to occur does not replace the need for a governance and strategy to disrupt unsustainable systems. The occurrence of windows of opportunity can have a significant effect on a transition process (Herrfahrdt-Pähle et al., 2020). However, Frank et al. (2024) have recently argued that a focus on punctuated equilibrium understandings of change and the window metaphor may not be helpful to understand the continuous nature of transition processes. Therefore, we argue that exnovation governance should, rather than waiting for the right moment, be actively pursued to support a shift towards climate-friendly agriculture.

A key limitation of our study is its focus on national government as the key actor to push the exnovation of peatland drainage. While much of the conceptual and empirical work in sustainability transitions takes a more bottom-up perspective (Turnheim and Sovacool, 2020), the literature on peatland governance on which we build here, centres on (national) government policy, as do – naturally – the policy strategies analysed in Section 5. Socio-technical change is, however, not neatly manageable by central governments (Johnstone and Newell, 2018; Kern

and Howlett, 2009). However, we contend that our concept of exnovation governance lends itself to analyses of much broader sets of actors and processes. As widespread rewetting is being adopted as a policy target, exnovation needs to become a mission for agricultural innovation systems (Klerkx and Begemann, 2020). More research is therefore needed on the required capacities of both states and other actors within such innovation systems (*ibid.*).

While we have focused on the German case here, the conceptual considerations are of general importance for countries with a large quantity of drained peatlands under agricultural use. Equally, the approach offers perspectives on agricultural governance at the level of the European Union and can be further spelled out to assess the close interactions between the EU and national levels (*cf.*, Frank and Schanz, 2022). In Europe, peatlands are also drained and used for forest, settlements, infrastructures and peat extraction (energy and horticulture) (Succow and Joosten, 2001; Tanneberger et al., 2021b). But since European peatland is mainly drained for agricultural reasons, we focused our analysis on this land use form. For further research it could be interesting to shed light on the nexus between peat usage or peatland drainage for other land use forms (e.g. forest, peat extraction and settlements) and exnovation governance.

With regard to the German case, we conclude that very recently, peatland rewetting is gaining more and more salience. The 2022 adopted National Peatland Protection Strategy (BMUV, 2022) and the Federal-Länder-target agreement from 2021 (BMEL and BMU, 2021) show that policymakers appreciate the complexity and need for a broad range of measures to govern this transition. Nevertheless, key elements of exnovation processes, which were suggested by research reports on peatland emissions or derived from conceptual exnovation literature, are absent in this policy strategy and implementation. With their analysis of the perceived legitimacy of agricultural transitions, Boon et al. (2022) stress, that a voluntary approach without a clear and enforceable regulatory baseline seems not suitable to gain perceived output legitimacy. The National Peatland Protection Strategy raises the prospect of an adjustment of the political strategy as well as realigning and straightening the legal framework after an evaluation in 2025. For this process, an exnovation perspective can provide guidelines and orientation.

As exnovation governance involves far-reaching and incisive policies. It must therefore be well-crafted and based on scientific evidence and facts, and not captured by particular (self-) interests, such that the governance and implementation processes remain credible and transparent for all stakeholders. Further, a policy-guided transition implies the assumption that governments have information about the future and about the best and most sustainable

technologies on which to base their policies. However, uncertainty regarding knowledge and openness to technology should be considered here. For a successful disruption process acceptance within society and stakeholders is important. But for the policy design of peatland drainage phase-out the challenge is to also consider the time pressure due to emission reduction and climate protection targets as well as the needed time to create acceptance and adjust for the transition. Buschmann et al. (2020) state in their work that peatland protection measures not only depend on an institutional framework but also on local factors, context and consent of local stakeholders.

The classification of peatland rewetting as an issue of exnovation opens up a broad field of research to discuss this case with further theoretical approaches. Following this framework, a comparison of peatland rewetting as a socio-technical transition in different peatland- rich countries could be fruitful for both policy and science.

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## CHAPTER 2

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# CHAPTER 3

## DERIVING A JUSTIFIED BUDGET FOR PEATLAND REWETTING – APPLYING THE GERMAN COAL PHASE-OUT AS A BLUEPRINT

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Published in *Land Use Policy* 147 (2024) 107363

<https://doi.org/10.1016/j.landusepol.2024.107363>

Changes that have been made compared to the published article:

- Table 1, second column has been corrected to: “Peatland area in ha” instead of “Peatland area in km<sup>2</sup>”
- Numbering of the appendix to harmonise the dissertation text as a whole



## Abstract

Carbon emissions of peatlands drained for agriculture and forestry contribute more than 7 % to total GHG emissions in various countries worldwide. Hence, reducing these emissions by ending peatland drainage is a significant contribution to a transition towards carbon neutrality and being in line with the Paris Agreement. To achieve this goal, swift action is needed. Using Germany as a case study, we scrutinize whether the German coal phase-out can serve as a ‘blueprint’ to end drainage on agriculturally used peatlands, using six categories (political, economic, social, technological, environmental, and legal). We also calculate a politically justified budget for a peatland drainage phase-out comparable to the coal phase-out in terms of the socially acceptable mitigation of CO<sub>2</sub> emissions. Our results suggest that the current pace of rewetting is too slow in comparison to a rewetting path following the Paris Agreement and would create an area gap of about 560,000 ha and a resulting CO<sub>2</sub> emission gap of 84.6–148 Mt CO<sub>2</sub> by 2029. We show that both, peatland drainage phase-out and coal phase-out, are socio-technical transitions which require governmental intervention and a guided-level perspective. For a governed peatland drainage phase-out in Germany which is 1.5°C compatible, we determine a politically justified total budget between 13.8 and 16 billion €.

**Keywords:** Peatland rewetting; Carbon neutrality; Land use policy; Peatland drainage phase-out; Sustainable transition; Socio-technical transition

## 1. Introduction

In 2015, the Paris Agreement set the target to limit the increase of global average temperature to 1.5°C above pre-industrial levels (UNFCCC, 2015). To this end, greenhouse gas (GHG) emissions have to be reduced substantially (Rocha et al., 2015) until carbon neutrality is reached (Chen, 2021). Countries worldwide have taken formal steps to adopt, announce, or consider carbon neutrality goals in alignment with the Paris Agreement (Chen, 2021; UNEP, 2020). Countries with a climate framework law are e.g. Denmark, France, Germany, Mexico, New Zealand, Sweden, and the UK (CCC, 2020). In order to restrict climate change and follow the 1.5°C target the global cumulative anthropogenic CO<sub>2</sub> emissions should not exceed a defined global carbon budget (Huang and Zhai, 2021; IPCC, 2021a, 2021b). Emission reduction is necessary in all sectors as well as further improvement of carbon sinks to reach carbon neutrality as soon as possible (Chen, 2021; IPCC, 2021b). This also includes emissions from drained organic soils, reported in the land use, land-use change, and forestry (LULUCF) sector of GHG inventories (Qiu et al., 2021). When drained - mainly for agricultural or forestry

purposes - soil organic carbon is oxidised to CO<sub>2</sub> and continuously released into the atmosphere. In countries like Finland, Germany, Indonesia, Ireland, Poland, and Russia these emissions contribute to more than 7 % of their total emissions (Crippa et al., 2024; UNEP, 2022, see also Table 1 below).

Rewetting peatlands is an effective measure to stop soil-borne CO<sub>2</sub> emissions (Wilson et al., 2016) and move toward carbon neutrality (Günther et al., 2020; Humpenöder et al., 2020; Leifeld et al., 2019; Leifeld and Menichetti, 2018; Tanneberger et al., 2021a). But rewetting also poses challenges for farmers such as high opportunity costs and low economic incentives to rewet, missing planning reliability as well as conventional farming methods can no longer be applied and have to be adapted to wet conditions (Tanneberger et al., 2020). Which in turn leads to important socioeconomic consequences (Buschmann et al., 2020; Schaller, 2011). Previous investments and decisions caused social and technological lock-in effects to drained peatland farming practices, which reinforce themselves as established technologies and practices offer advantages over new market participants, resulting in a path dependency that limits future decisions and actions (Arthur, 1989; Liebowitz and Margolis, 1995; Ziegler et al., 2021; Sommer and Frank, 2024). Due to a long history of peatland drainage, the practice is anchored in society and culture as well as in peatland farmers' and communities' identity building (Deickert and Piegsa, 2016). These aspects lead to the conclusion that rewetting is a profound transition process which we understand as a 'socio-technical transition' by following the sustainable transition literature (Geels, 2011; Rinscheid, 2021; Loorbach, 2017).

In order to meet the climate targets, the pace of peatland rewetting has been rather slow (Barthelmes et al., 2021; Leifeld et al., 2019) and the political awareness necessary to accelerate rewetting seems insufficient (Abel et al., 2019; Grethe et al., 2021; UNEP, 2022). Since agriculture on drained peatland is established in many peatland-rich countries (UNEP, 2022), these countries will meet the challenge of initiating and governing the phasing out of peatland drainage for agriculture (peatland drainage phase-out). By phase-out we refer to the sequential cessation of technologies and practices that cause negative externalities (Rosenbloom and Rinscheid, 2020; Trencher et al., 2022a). The phase-out has a specific, politically given timeframe and a complete abandonment of the unsustainable practice or technology at its endpoint (Trencher et al., 2022b).

**Table 1. Comparison of peatland area and emissions and GDP per capita in a selection of peatland rich countries.**

| Country                | Peatland area in ha | Share of drained peatland area of total peatland area | Emissions from drained peatlands in Mio. t CO <sub>2</sub> e | Emissions from drained peatlands under agricultural use in Mio. t CO <sub>2</sub> e | GDP per capita, PPP 2022 (constant 2017 international \$/person) |
|------------------------|---------------------|-------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------|
| Germany                | 1,838,779           | 90%                                                   | 53                                                           | 43                                                                                  | 53,970                                                           |
| UK                     | 2,683,000           | 50%                                                   | 30                                                           | not available                                                                       | 47,587                                                           |
| Poland                 | 1,509,000           | 85%                                                   | 31                                                           | 27                                                                                  | 37,707                                                           |
| Ireland                | 1,454,000           | 80%                                                   | 22                                                           | 15                                                                                  | 112,445                                                          |
| Finland                | 8,313,000           | 60%                                                   | 37                                                           | 10                                                                                  | 49,419                                                           |
| Estonia                | 245,900             | 75%                                                   | 14                                                           | 10                                                                                  | 37,712                                                           |
| Latvia                 | 158,320             | 74%                                                   | 12                                                           | 7                                                                                   | 32,992                                                           |
| Lithuania              | 283,400             | 68%                                                   | 10                                                           | 8                                                                                   | 39,955                                                           |
| Indonesia              | 20,949,000          | 55%                                                   | 700                                                          | not available                                                                       | 12,410                                                           |
| Russia (European part) | 20,800,000          | 45%                                                   | 231                                                          | not available                                                                       | 27,450                                                           |
| USA                    | 38,813,000          | 5%                                                    | 47                                                           | not available                                                                       | 64,623                                                           |
| Canada                 | 119,377,000         | <2%                                                   | 42                                                           | not available                                                                       | 48,975                                                           |

**Source:** Based on UNEP (2022); GMC (2023); World Bank (2023).

For our investigation, we choose Germany, as it has an ambitious climate law as well as the highest share of drained peatland area of total peatland area in Europe (Table 1; GMC, 2023; UNEP, 2022). The German Federal Climate Change Act (Climate Act) sets sector-specific targets defining gradual reductions in GHG emissions up to GHG neutrality in 2045 (BMU, 2021a). The amendment of the LULUCF EU regulation (EU, 2023) and the German Climate Act require an improvement of the LULUCF sink performance (BMU, 2021a). While the carbon sink capacity of forests is decreasing, the quantity of emissions from drained peatland in Germany remains constant at approx. 53 Mt CO<sub>2</sub>e equivalents (CO<sub>2</sub>e) per year (p.a.), resulting in a LULUCF sector which becomes most likely an overall GHG source in 2025 (BMU, 2021b). Therefore, peatland drainage phase-out is highly important to reach LULUCF targets as a contribution to carbon neutrality. As approximately 70–75 % of drained peatlands (Tanneberger et al., 2021b) are used in Germany for agriculture (UBA, 2022), the peatland drainage phase-out will primarily mean a paradigm shift in the agricultural sector. The question arises of how the peatland drainage phase-out as a transition process could be governed in a socially acceptable and just way. Moreover, Germany has introduced a transformation scheme for phasing out exploitation of lignite coal (coal phase-out) to reduce emissions in the energy sector. The transition of the lignite industry and mining areas was politically decided and is

currently underway. In this paper, we investigate, whether the transition of the lignite industry can serve as a blueprint for the peatland drainage phase-out.

To this end, our paper has three objectives. Firstly, we analyse the similarities and differences between the lignite and agricultural sector to check whether the coal phase-out is a blueprint for peatland drainage phase-out. A PESTLE analysis is used for a comparison within the six categories: political, economic, social, technological, legal, and environmental to provide an overview of the broad environment influencing the two sectors and allows for an overview from multiple perspectives. Although PESTLE is rooted in marketing analysis, this framework is applied to elaborate the elements that shape the sectors and understand challenges from multiple perspectives, as Achinas et al. (2019) did for the biofuels energy industry in Europe or Ricci et al. (2021) to conceptualise the challenges facing cybersecurity education. Secondly, we analyse the difference between the current pace of rewetting and political climate targets. Thirdly, we derive the ‘political willingness to pay (pWTP)’ and a politically justified budget for a 1.5°C compatible peatland drainage phase-out from the coal phase-out using an explorative calculation based on the coal phase-out. The latter serves as a ‘political role model’ or counterfactual scenario because it is a key politically induced sustainable transition measure in the German energy sector. The budget results from the financial resources spent on CO<sub>2</sub> savings.

## **2. Methods**

### **2.1. Similarities and differences between coal and peatland drainage phase-out**

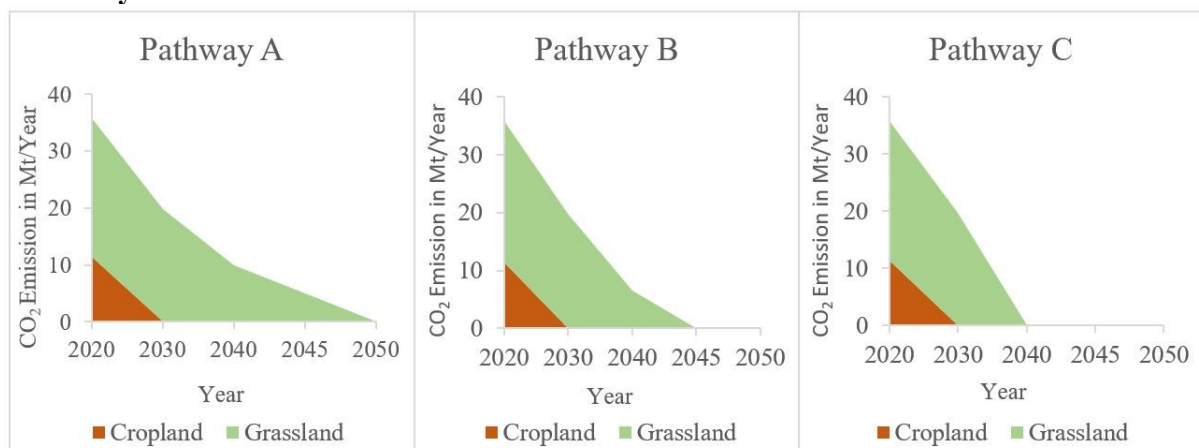
To examine the similarities and differences between the coal phase-out in the lignite industry (hereafter short: ‘coal phase-out’) and the peatland drainage phase-out in Germany, we used the PESTLE framework (Homburg, 2017; Schomaker and Sitter, 2020) to analyse the industries to consider from multiple perspectives the broad environment the sector is facing (e.g. Achinas et al., 2019; Ricci et al., 2021). It allowed us to analyse the relationships between economic development and institutional conditions of our relevant business environment and included the current macro-environment of our industry as well as projected future developments (Homburg, 2017; Schomaker and Sitter, 2020). We presented outcomes for each of the six dimensions of PESTLE to deepen the understanding of rewetting as a change in a

socio-technical regime<sup>6</sup> (cf., Ziegler, 2020; Sommer and Frank, 2024). Geels (2011, p. 24) emphasized that addressing contemporary environmental problems calls for deep structural changes also in the agri-food system. He describes these changes as socio-technical transitions because they involve changes in the overall configuration (technology, policy, markets, consumer practice, infrastructure, cultural meaning and scientific knowledge). Loorbach et al. (2017, p. 605) contribute to this understanding by highlighting "path dependency and lock-in of existing socio-technical systems around specific technologies" which further justified the phase-out approach as a governance strategy towards a rewetting pathway in line with the Paris Agreement. As Rinscheid et al. (2022, p. 225) define 'phase-out as a policy intervention that deliberately seeks to terminate one or several socio-technical elements (e.g., technologies, substances, processes or practices) in a gradual or stepwise process'.

## 2.2. Rewetting pathways

We develop three scenarios as rewetting pathways for Germany (Fig. 1).

**Figure 1: Three pathways to rewet drained peatlands under agricultural use in Germany.**



**Source:** Own illustration. Pathway A is according to pathway 2 of Tanneberger et al. (2021a).

We focused on peatland of the categories 'grassland' and 'cropland' only, as ca. 83 % of the total CO<sub>2</sub> emissions originate from them. We denoted the pathway of Tanneberger et al.(2021a) as pathway A. Based on the German Climate Act's climate neutrality target by 2045 (BMU, 2021a), we developed a (more ambitious) second pathway denoted pathway B. A third (most ambitious) pathway based on the rewetting of all cropland and grassland already by 2040 is denoted pathway C. The latter may be the pathway that needs to be implemented to achieve

<sup>6</sup> We define the socio-technical regime as '[...] comprised of stable, mutually- supporting linkages between technologies, policies, user practices, scientific knowledge, cultural categories, and financial arrangements.' Roberts (2017, p. 87).

climate neutrality in 2045/2050 if other sectors fail to sufficiently reduce their emissions. All three pathways start in 2020 and have the same amount of CO<sub>2</sub> reduction in 2020–2029 following the pathway according to Tanneberger et al. (2021a), as we assume that several years of planning and capacity building are needed to achieve the necessary average rate of rewetting. To specify gaps in emission reduced and area rewetted, we limited our considerations to the period 2020–2029, which as we noted, is the same in all three pathways. We used 2000 ha as an estimate for the current annual rewetted area in Germany, which constitutes the average annual rewetted area since 1980 (Barthelmes et al., 2021). In our calculations the rewetting pathways aimed to bring CO<sub>2</sub> emissions down to net zero even though the emission factor from IPCC (2014) and Tiemeyer et al. (2020) indicate an emission factor of rewetted areas for CO<sub>2</sub> in Germany below zero (which means to absorb CO<sub>2</sub>). We conservatively exclude CO<sub>2</sub> sequestration after rewetting from our calculation due to the fact, that not all rewetted areas can sequester CO<sub>2</sub> after rewetting again (Bianchi et al., 2021; Renou-Wilson et al., 2016). The three pathways consider only CO<sub>2</sub> since in the case of peatlands, the radiative forcing effects of CH<sub>4</sub> and N<sub>2</sub>O, i.e. the other two GHGs related to peatlands, are relatively small compared to those of CO<sub>2</sub> (Günther et al., 2020). Furthermore, a CO<sub>2</sub>-only approach is also relevant as the basis for estimating a nation's carbon budget (IPCC, 2021a; SRU, 2020). The carbon budget with its limited amount of still permitted CO<sub>2</sub> emissions led to a time-dependent drastic reduction of annual emissions (IPCC, 2018). The carbon budget approach is suitable to evaluate, if emission-reducing policy goals and progress are compatible with the Paris Agreement (SRU, 2020). Further, we calculated a politically justified budget to contribute to a Paris-compatible emission reduction.

### **2.3. Politically justified budget**

#### *2.3.1. Assumptions*

In this section, we outlined the assumptions used to exploratory calculate the politically justified budget. While the coal phase-out is a non-linear process with agreed terms at what date coal-fired power stations are taken off the grid, the proposed rewetting phase-out is a step-wise, linear process. In order to make them comparable, we transfer the coal phase-out into a linear process by taking the following steps.

First, we argued that political willingness to pay (pWTP) for CO<sub>2</sub> emission reductions due to lignite coal phase-out can be derived from the financial budget agreed for it. Hence, the pWTP for coal phase-out can be scaled to eliminate an annual CO<sub>2</sub> emission source. Second, we considered a discount rate ( $r$ ) to express the budget and pWTP in present values (PV). Third,

we transferred the pWTP derived from the coal phase-out to the peatland drainage phase-out. Finally, we stated why we considered only CO<sub>2</sub> in our approach.

1. The coal phase-out has a clear objective and a strategy with a corresponding budget and was determined and legally enshrined by parliament (Bundestag, 2020a, 2020b). Hence, the budget set by parliament - as the people's representation in a democratic system - can be seen as the political willingness to pay to achieve the objectives of coal phase-out. According to the methodological convention of the German Federal Environment Agency, criteria to define a pWTP are fulfilled (UBA, 2018): The parliament, representing the will of the population (i) agreed upon a clear general goal and the steps to achieve the goal, (ii) determined the costs of the bundle of measures necessary to achieve the goal and (iii) downscaled these costs corresponding to the pollutant unit (i.e. avoided ton of CO<sub>2</sub>). We refrained from analysing a more ambitious target year for the coal exit than 2038 while we focused on the overall package of financial volume and legally anchored coal phase-out in 2020. To calculate the pWTP in € per ton of CO<sub>2</sub> along the coal phase-out pathway, we used different means of coal phase-out according to Haywood et al. (2021) as well as the respective laws (Bundestag, 2020a, 2020b). These included compensation payments, structural support, and adjustment funds for employees. Electricity price compensation and the purchase of emissions permits were not included in the calculation. Such financial resources are strongly intertwined with the phase-out of hard coal and there are major uncertainties regarding their financial implications (2019). To quantify the pWTP for the coal phase-out, CO<sub>2</sub> emissions reductions along the legally adopted pathway of the coal phase-out for 2020–2038 were determined by the corresponding power plant closures as listed in Appendix A2. Data on emissions from individual power plants are from Öko-Institut (2020b). Emissions mitigation potential per power plant was then converted to cumulative emissions reductions by 2050 as reported in Appendix A2 and A3.

2. The budget for the coal phase-out was set in 2020, we assumed that stakeholders anticipated a discount rate while negotiating the total budget for the coal phase-out. So, the final set budget is expressed in the present value of the year 2020. The concept of discounting allowed us to compare effects which occur at different future times (Weitzman, 2001). To calculate the present value of mitigated tons of CO<sub>2</sub> we applied a discount factor (DF). We set the discount rate at 2 %. Considering the debate and uncertainties about which discount rate to choose (Arrow et al., 2014), we additionally presented our results for a 1 % and 3 % discount rate in Section 3.3 to show the sensitivity. For more details please refer to the supplementary material (see Appendix A3 – Table A3.2 to A3.4).

3. Based on the pWTP to eliminate an annual source of one ton of CO<sub>2</sub> via coal phase-out, a politically justified budget for rewetting all cropland and grassland areas on peatlands was derived for the three rewetting pathways, A, B and C. To determine the politically justified budget, the annual CO<sub>2</sub> emissions mitigated by the coal phase-out pathway and the rewetting pathways were summed up to 2050, respectively. Due to a common start and end point, our pathways compared well.

4. To use the pWTP both for coal and peatland drainage phase-out, we referred to the idea of a ‘remaining carbon budget’ or ‘cumulative budget of CO<sub>2</sub>’ (Huang and Zhai, 2021; IPCC, 2021a) which assumes that a certain total amount of emissions can be emitted under a 1.5°C target. The contribution to the carbon budget is then dependent on the time at which an annual source of CO<sub>2</sub> is eliminated: a coal power plant is shut down or a peatland area is rewetted. It considers that in both cases, emissions come from processes that continuously emit CO<sub>2</sub>. Every ton of CO<sub>2</sub> reduced by shutting down a coal-fired power plant or rewetting a specific area of peatland is then not emitted in subsequent years. The sooner an annual source of emission is eliminated by for example a coal-fired power plant’s shutdown or the rewetting of peatland, the larger the mitigation contribution of CO<sub>2</sub> (Oei et al., 2018). We applied a CO<sub>2</sub>-only approach and restricted our consideration and calculation to CO<sub>2</sub>. This is justified by CO<sub>2</sub>’s considerable radiative forcing effect and persistence, typically remaining in the atmosphere for over 1000 years as well as focusing on the concept of carbon neutrality (Chen, 2021; Günther et al., 2020; IPCC, 2021b).

### 2.3.2. Exploratory calculation

The CO<sub>2</sub> emissions of source  $i$  in year  $t$  are represented by  $X_{it}$ , where  $t_0 = 2020, \dots, t, \dots, T = 2050$  as well as  $i, \dots, N$ . Since we were interested in the willingness to pay for mitigated CO<sub>2</sub> emissions, we defined the reduction as absolute value in relation to the previous year:

$$\Delta X_{it} = |X_{it} - X_{i,t-1}| \quad (1)$$

Summing up all avoided emissions until the end of the pathway from all sources yields the overall CO<sub>2</sub> emissions mitigation potential,  $Z$ :

$$Z = \sum_i^N \sum_{t_0}^T \Delta X_{it} \quad (2)$$

Consequently, an earlier elimination of an (annual) CO<sub>2</sub> source accumulates in higher mitigated CO<sub>2</sub> emission at the end of the pathway.

While we knew the given points in time when lignite coal power plants were shut down as well as the present value of the total budget,  $B$ , (or discounted total budget) for the coal phase-out,

the share of the budget,  $b_{it}$ , to compensate for the annually mitigated emissions was unknown.

The present value of the total budget is given by

$$B = \sum_i^N \sum_{t_0}^T b_{it} \cdot DF_t = 45.8 \text{ bn EUR} \quad (3)$$

where  $DF_t = (1 + r)^{-t}$  with  $r = \{0.01; 0.02; 0.03\}$  as discount rates. The discount rate also reflects that an avoidance of emissions is attributed a higher budget in present values.

As we assumed that the political willingness to pay (pWTP) to mitigate one ton of CO<sub>2</sub> is constant over time, the pWTP is defined as the budget assigned to this avoided ton. Formally, we could derive the pWTP for the coal phase-out,  $pWTP_r^{coal}$ , as follows:

$$pWTP_r^{coal} = \frac{B_r}{\text{Total avoided emissions}} = \frac{\sum_i^N \sum_{t_0}^T b_{it}}{Z} \quad (4)$$

With  $B_r$  is the total undiscounted budget and unknown budget.

Using the information from equations (3) and (4), the following condition needed to hold

$$45.8 \text{ bn EUR} = \sum_i^N \sum_{t_0}^T DF_t \cdot \Delta X_{it} \cdot pWTP_r^{coal} \quad (5)$$

In the case without any discount rates, the value for  $pWTP_r^{coal}$  was straightforward as it is simply the average of the total budget,  $B_r$  assigned to the accumulated avoided carbon dioxide over time until the end of the pathway.

Having calculated  $pWTP_r^{coal}$ , the values were used to determine the politically justified budgets for the rewetting pathways A, B and C.

$$B_{rm}^{rewetting} = \sum_i^N \sum_{t_0}^T DF_t \cdot \Delta X_{itm}^{rewetting} \cdot pWTP_r^{coal} \quad (6)$$

where  $m = \{A; B; C\}$  are the different rewetting pathways described above.

Further should be noted, that the justified Budget to eliminate an annual CO<sub>2</sub>-emissions source in  $t$ ,  $jb_{rt}^{annual \text{ source}}$  is:

$$jb_{rt}^{annual \text{ source}} = \sum_{t_0}^T DF_t \cdot pWTP_r^{coal} \quad (7)$$

The result is, that the annual budget  $b_{rtm}^{rewetting}$  along the rewetting pathways could be calculated as follows:

$$b_{rtm}^{rewetting} = jb_{rt}^{annual \text{ source}} \cdot \Delta X_{itm}^{rewetting} \quad (8)$$

### 3. Results

#### 3.1 Comparison of coal phase-out and peatland drainage phase-out

The short literature review based on the PESTLE framework shows many similarities between both transitions but some significant differences as well (Table 2).

**Table 2. Applicability of criteria used in the comparison of coal phase-out and peatland drainage phase-out in the six dimensions of the PESTLE framework.**

| Political                                    |          |          | Economic                                   |          |          | Social                                           |          |          |
|----------------------------------------------|----------|----------|--------------------------------------------|----------|----------|--------------------------------------------------|----------|----------|
|                                              | <u>C</u> | <u>D</u> |                                            | <u>C</u> | <u>D</u> | <u>C</u>                                         | <u>D</u> |          |
| International climate agreements             | x        | x        | Geographic concentration                   | x        | x        | Affected by structural change                    | x        | x        |
| Established policy instruments               | x        | x        | Few, homogeneous and big companies         | x        | -        | Significant decline in employment                | x        | x        |
| Legally binding strategy                     | x        | -        | Mandatory carbon market                    | x        | -        | High wage level                                  | x        | -        |
| Existing mix of instruments                  | x        | -        | Rising economic pressure                   | x        | -        | High share of elderly workforce                  | x        | x        |
| Fixed time horizon                           | x        | -        | Fear of potential economic damage          | x        | x        | High historical and cultural value               | x        | x        |
| Mandatory measures                           | x        | -        | Minor role in the overall economy          | x        | x        | Acceptance of phase-out                          | x        | -        |
| Civil society movement                       | x        | -        | Importance for regional economy            | x        | x        |                                                  |          |          |
| Legal framework and promotion of alternative | x        | -        | Receive direct and indirect subsidies      | x        | x        |                                                  |          |          |
| Technical                                    |          |          | Legal                                      |          |          | Environmental                                    |          |          |
|                                              | <u>C</u> | <u>D</u> |                                            | <u>C</u> | <u>D</u> |                                                  | <u>C</u> | <u>D</u> |
| Oxidation of carbon stored in the ground     | x        | x        | Sector-specific emission reduction targets | x        | x        | High CO <sub>2</sub> emissions                   | x        | x        |
| Emission reduction is realized immediately   | x        | x        | Encroachment on property                   | x        | x        | Emission of other pollutants                     | x        | x        |
| Technical alternative is established         | x        | -        | The principle of voluntariness             | -        | x        | Negative impact on the condition of water bodies | x        | x        |
|                                              |          |          | Legally anchored and shaped by an Act      | x        | -        | Contribution to climate adaptation               | -        | x        |
|                                              |          |          |                                            |          |          | Prevent further damage to environmental media    | x        | x        |

**Source:** Own presentation. Criteria within six PESTLE categories. x applicable and – notes, that the criteria are not applicable for coal phase-out (C) or peatland drainage phase-out (D). Criteria are in order of occurring in the results section.

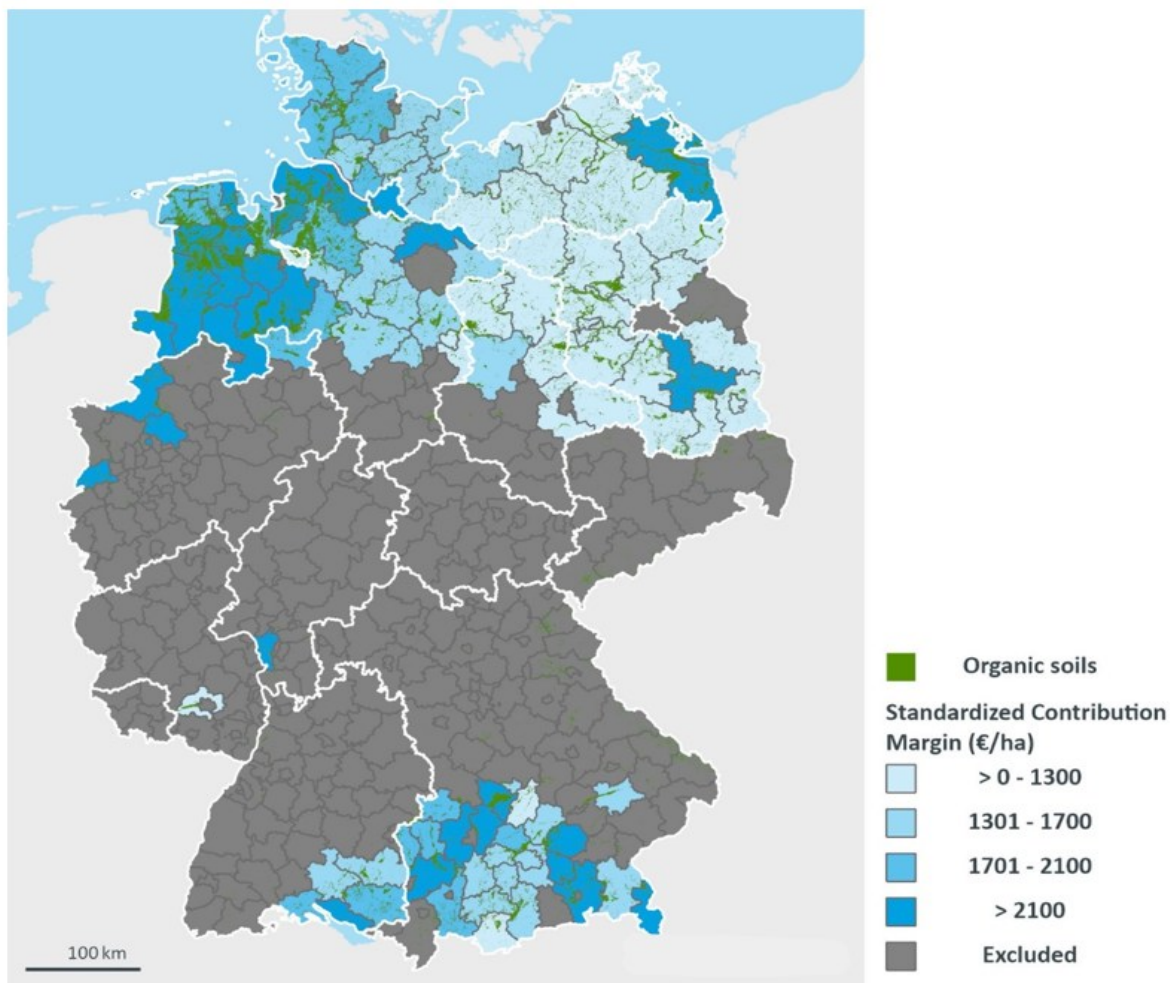
The political dimension (P) provides some similarities. Occurring differences are mainly led back to currently missing governance in the case of peatland drainage phase-out. International climate agreements and legal obligations such as the EU Climate Change Act (EU, 2021) and

the National Climate Act (BMU, 2021a) are in place and it is suggested to use the significant emission reduction potential in both industries (BMUV, 2022b; Oei et al., 2018; UBA, 2022). For both options, there are established policy instruments at the EU level such as the European emission trading scheme (EU ETS) and the Common Agricultural Policy (CAP) in the European Union that shape and support the coal phase-out and potentially could do so for the peatland drainage phase-out, respectively. In contrast to the coal phase-out, the national process for peatland rewetting is currently based on a non-specific strategy (Grethe et al., 2021). The only specified target is to reduce the annual GHG emissions from drained peatlands by at least 5 Mt of CO<sub>2</sub> by 2030 (BMUV, 2022b). However, the conception and anchoring of a legally binding long-term strategy with a corresponding mix of instruments and a fixed time horizon for rewetting is missing.

The pathway for a socially acceptable coal phase-out and the optimal policy mix has been politically determined by the ‘Commission for Growth, Structural Change and Regional Development’ (short: ‘Coal Commission’) (BMWK, 2019) and resulted in a Coal Phase-Out Act (BMWi, 2020; Bundestag, 2020a, 2020b). In the case of peatland rewetting, the political toolbox is currently limited, as the principle of voluntariness has politically adhered to date. Compared to the coal phase-out (Sander, 2016; 2019), the call for widespread rewetting and paludiculture has not been accompanied by a strong civil society movement but is rather science-driven (Ziegler et al., 2021). The legal course and promotion to develop alternatives of renewable energies as an alternative to coal-fired power generation has already taken place since 1991 (Wichmann et al., 2022a). In the case of alternatives to drainage-based peatland use, there has been no similar transformation of the legal framework and legal promotion so far (Wichmann et al., 2022a). On the contrary, there continues to be legal and financial support for peatland drainage, e.g. under the CAP (Wiegmann et al., 2023).

From an economic point of view (E), a significant similarity between the coal industry and agriculture on drained peatlands is the geographic concentration: The three main lignite mining areas extend over six federal states (Oei et al., 2018); the peatlands are concentrated primarily in five federal states (Nordt et al., 2022). A significant difference is the number, structure, and size of the companies or groups as political actors (Bundestag, 2021; Oei et al., 2018; Öko-Institut, 2017): Three companies operate in the three remaining lignite mining areas. The large number of companies operating on peatlands is heterogeneous in terms of size, orientation, and operational structure (Schaller, 2014). Also, there are higher opportunity costs in the Northwest and South due to the high regional value added from animal production compared to the Northeast of Germany (Röder and Grützmacher, 2012) (Fig. 2).

**Figure 2. Standardised contribution margin (€/ha) of agriculture on drained peatlands in Germany (district level) weighted as a share of peatland area of the total agriculturally used area.**



**Sources:** Own illustration, based on the map of organic soils from Tegetmeyer et al. (2021), standardised contribution margin calculated based on KTBL (2020), Destatis (various years), and Neuenfeldt et al. (2020). Colour distribution according to quartiles of standardised contribution margin at the district level. Districts with more than 4,000 ha of agriculturally used organic soils or more than 4 % of the district's agriculturally used area.

The lignite industry is part of the mandatory emission trading scheme, while agriculture is not. Due to rising prices for CO<sub>2</sub> certificates over time (Pietzcker et al., 2021), lignite-based power generation is expected to become less profitable in the long run (Öko-Institut, 2020a). In contrast, key policy instruments relevant to agriculture, such as the CAP, have so far not provided sufficient incentives for peatland rewetting (Nordt et al., 2022; Wiegmann et al., 2023). There exists a fear of potential economic damage from stopping peatland drainage and coal electricity among the stakeholders, respectively (Fiedler and Schrems, 2020; Schaller, 2014; Wichmann et al., 2022a). However, there is a general difference, as rewetted peatlands do not have to be removed from use as a logical consequence, since the possibility to use the

area under wet conditions is initially open for farmers. Whereas the lignite-fired power plants are intended to shut down.

Both the lignite industry and agriculture consider themselves significant contributors to the security of supply (for electricity (BMWK, 2019) and food (ZKL, 2021), respectively). Measured by the national gross value added, the lignite industry (0.2 % in 2016) (RWI, 2018) and agriculture (0.6 % in 2018) (Statista, 2021) play rather a minor role in the overall economy. Regionally, the role can be larger and could affect the regional economy due to a regional concentration on a few federal states of peatlands as well as lignite-fired power plants (Isermeyer et al., 2019; Oei et al., 2018).

Both industries receive direct and indirect subsidies: Especially due to tax incentives for energy taxation and exemption from extraction and water withdrawal fees, energy from lignite was subsidised by 1.7 billion € in 2016 (Parry et al., 2021; UBA, 2021b; Wronski and Fiedler, 2017). Subsidies and tax-reliefs for the whole agriculture sector amount to ca. 13.6 billion € p.a. in Germany, including 3.8 billion € for social security in the agricultural sector (BMEL, 2021; BMEL, 2023; 28AD). On 1,285,083 ha drained peatland under agricultural use (Nordt et al., 2022), ca. 198 million € p.a. will spend 2023 - 2027 as area-based direct payments<sup>7</sup> (BMEL, 2023).

The social dimension (S) shows that both the lignite industry and agriculture are affected by structural change for decades, with, among others, a significant decline in employment (Bundestag, 2021; Oei et al., 2018). Whereas the wage level differs, as the lignite sector counts as a high-wage sector (Oei et al., 2018) and agriculture not (Bundestag, 2021), both sectors show a similar demographic structure with a disproportional share of elderly workforces (DBV, 2021; Oei et al., 2018). Therefore, a large share of the currently employed will probably retire without a break in their employment biography (Sander et al., 2020) even in the event of a coal phase-out or peatland drainage phase-out.

In terms of social and cultural considerations, both lignite-fired power generation and peatland drainage are established, have a high value, and the workforce feels a strong attachment to these practices (Deickert and Piegsa, 2016; Sander et al., 2020). There is a preference (also in the affected regions) for a coal phase-out (Rinscheid and Wüstenhagen, 2019) and the public acceptance of damages caused by mining decreases (Matthes, 2021), but the initial conditions with which the affected regions face structural change vary greatly (Oei et al., 2018). Acceptance of peatland rewetting decreases with increasing operational impact (Krimly et al.,

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<sup>7</sup> Basic income support ranges between 158 and 149 €/ha between 2023 and 2027 (BMEL, 2023).

2016; Schaller, 2014) and is currently low due to missing knowledge and best practice examples of alternative use (Nordt et al., 2022).

The technological criteria (T) show similarities as well, as both, the coal phase-out and the peatland drainage phase-out aim to prevent the oxidation of carbon stored in the soil or in bedrock as CO<sub>2</sub> (Jurasinski et al., 2016; UBA, 2021a). And in both cases, the emission reduction is realised immediately by either stopping the burning of coal or by stopping the mineralisation of peat due to water levels raised to the surface (Jurasinski et al., 2016; Wilson et al., 2016).

Renewable energies are available as an alternative to coal-fired power generation. Through financial and legislative support renewable energies have established themselves in Germany for the last 20 years (Wichmann et al., 2022a). Paludiculture, i.e. agriculture and forestry on wet and rewetted peatlands, on the other hand, is still under development, has not yet been promoted on a large scale, and can be described as an infant industry (Tanneberger et al., 2020; Wichmann et al., 2022a).

Therefore, in contrast to coal combustion, which is already considered to be a phase-out model (Fiedler and Schrems, 2020), investment decisions in agriculture are still focused on the continued management of drained peatlands and do not distinguish between mineral and organic soils (Wichmann et al., 2022a). The continuous peatland drainage also leads to additional costs and yield reductions due to soil subsidence and degradation, and ultimately to a loss of soil as a production factor (Zeitz, 2016).

From a legal perspective (L), CO<sub>2</sub> emissions both from lignite combustion and from drained peatlands fall under a legal obligation with sector-specific emission reduction targets anchored in the National Climate Act (BMU, 2021a). The coal phase-out is an encroachment on property, which is justified due to a proportionality test (Wissenschaftliche Dienste, 2018). Concerning peatland rewetting, an encroachment on the property could be inferred, too. Under current land value assessment practices, a rewetted area has less property value (Wiegmann et al., 2023). National peatland-specific policies currently adhere to the principle of voluntariness to avoid encroachment on the property. This means that the (binding) climate protection targets will probably not be achieved (Grethe et al., 2021; Wichmann et al., 2022a).

The coal phase-out is mainly legally anchored and shaped by the Coal Phase-Out Act (Kohleausstiegsgesetz) (Bundestag, 2020a) and the Structural Development Act (Strukturstärkungsgesetz Kohleregionen) (Bundestag, 2020b). Peatland rewetting, on the other hand, is currently only described by target provisions and strategy documents, which are non-binding compared to the legal anchoring of the coal phase-out. The legally binding target for

the LULUCF sector in the German Climate Protection Law contains the peatland target only implicitly, as it looks at the sector in total (Grethe et al., 2021; Schäfer and Yilmaz, 2019).

The current management of the EU ETS is expected to drive or even bring forward the coal phase-out (Öko-Institut, 2020b; Pietzcker et al., 2021). Agriculture or even the LULUCF sector are not included in a mandatory emission trading system (Isermeyer et al., 2019). In the lignite industry, there is also a legal obligation to restore opencast mining areas, which is integrated into the investment calculations (Öko-Institut, 2017). In contrast, there is no similar obligation or permit requirement for peatland drainage (except for peat extraction), so appropriate financial resources for restoration are not held by agricultural stakeholders.

The environmental perspective (E) shows, that the negative climate impact of lignite-fired power generation and peatland drainage is mainly caused by high CO<sub>2</sub> emissions: 110.1 Mt of CO<sub>2</sub> from lignite-fired power plants in Germany in 2019 (Öko-Institut, 2020b) and 37.6 Mt CO<sub>2</sub> from drained peatlands (UBA, 2022). Both industries are also responsible for the emission of other pollutants - e.g. mercury, sulphur dioxide, and arsenic from coal burning (UBA, 2021a) and nitrous oxide as well as nitrate from drained peatlands (UBA, 2022).

Both the lignite industry and the drainage of peatlands have a negative impact on the condition of water bodies (Holsten and Trepel, 2016; UBA, 2021a). Rewetting, in turn, leads to an increase in water quality. Regarding climate adaptation, wet peatlands generate a local cooling effect and can better buffer flood and heavy rainfall events (Ahmad et al., 2020). Both coal phase-out and peatland drainage phase-out prevent further damage to environmental media such as soil, landscape, and biodiversity (Luthardt and Wichmann, 2016; UBA, 2021a).

The comparison shows the profound anchorage of peatland drainage practice within agriculture as a socio-technical regime (Markard et al., 2012; Roberts, 2017). Due to sunk investments the motivation for self-preservation is likely to proceed without policy intervention (Hoffmann et al., 2017; Trencher et al., 2022b). Furthermore, paludiculture as an innovation is still an infant industry, which cannot rapidly replace the established practice and the current design of subsidies does not provide sufficient economic incentives at the farm-level to stop peatland drainage. Under the given circumstances it is likely, that a market-driven exit supported by voluntary funding schemes for rewetting will not yield enough GHG savings within the required period to be in line with emission reduction targets (Grethe et al., 2021).

The PESTLE framework shows in both cases that exiting from the practice is also a paradigm shift and affects the social, cultural and political, institutional dimensions. In both cases exists a need and time pressure for change due to extensive environmental damages and the commitment to emission reduction. The comparison also shows that it is unlikely that rewetting

will occur for economic reasons or be market driven (fast enough) to meet the Paris Agreement, which requires government intervention.

To govern the transition as a multidimensional approach in line with the demand for a socially acceptable and just transition for peatland rewetting, the phase-out approach could be well suited to end peatland drainage as it has been for the coal phase-out (Markard et al., 2012; Rogge and Johnstone, 2017; Vögele et al., 2018).

### 3.2. Rewetting pathways

The phase-out approach calls for a specific, politically given timeframe and a complete abandonment of the unsustainable practice or technology at its endpoint (Heyen et al., 2017; Trencher et al., 2022b) but the current political strategy defines no final date for peatland drainage termination or specific pathway.

We define three pathways for the rewetting of agricultural peatlands in Germany, which differ in ambition and thus result in different levels of CO<sub>2</sub> emissions in the decades 2030–2039 and 2040–2049 (Table 3).

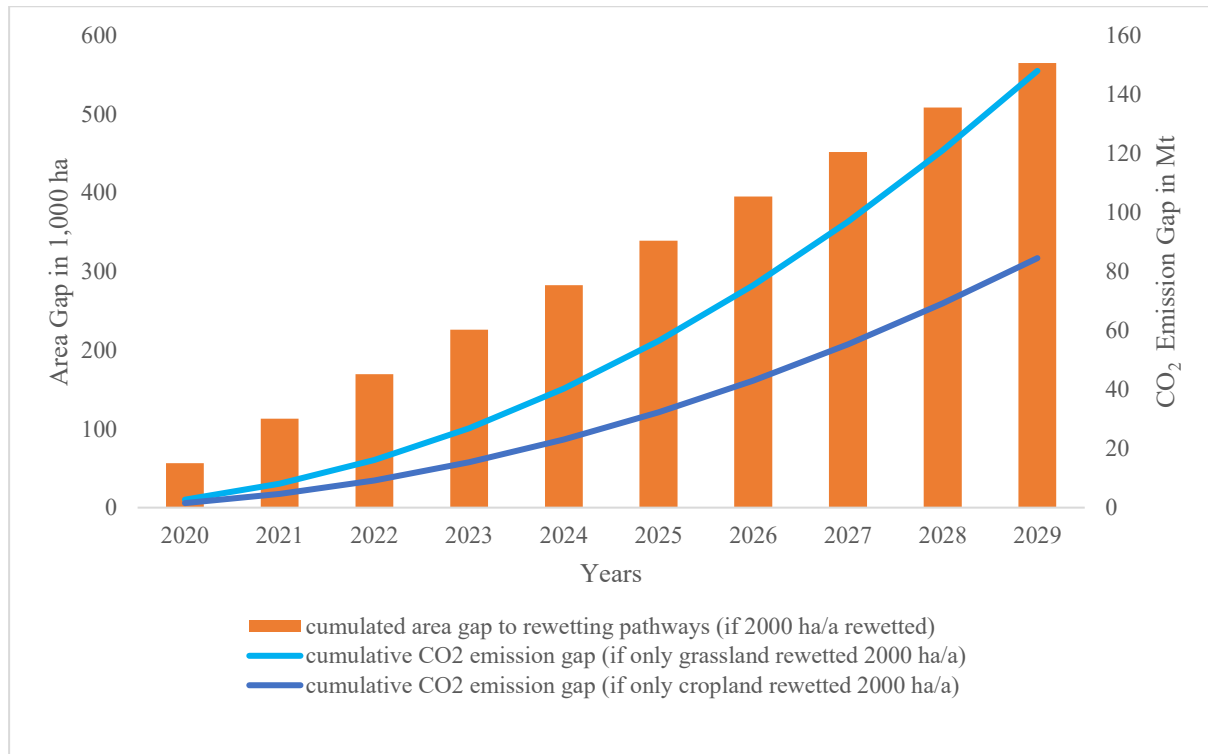
**Table 3. CO<sub>2</sub> emissions per year resulting from the rewetting pathways for agriculturally used peatlands in Germany in the period 2020-2050.**

| Emission in CO <sub>2</sub> (Mt) | Pathway A   |             |            |            |          | Pathway B   |             |            |          | Pathway C   |             |          |
|----------------------------------|-------------|-------------|------------|------------|----------|-------------|-------------|------------|----------|-------------|-------------|----------|
|                                  | 2020        | 2030        | 2040       | 2045       | 2050     | 2020        | 2030        | 2040       | 2045     | 2020        | 2030        | 2040     |
| Grassland                        | 24.4        | 19.8        | 9.9        | 5.0        | 0        | 24.4        | 19.8        | 6.6        | 0        | 24.4        | 19.8        | 0        |
| Cropland                         | 11.4        | –           | –          | –          | 0        | 11.4        | –           | –          | 0        | 11.4        | –           | 0        |
| <b>Total</b>                     | <b>35.8</b> | <b>19.8</b> | <b>9.9</b> | <b>5.0</b> | <b>0</b> | <b>35.8</b> | <b>19.8</b> | <b>6.6</b> | <b>0</b> | <b>35.8</b> | <b>19.8</b> | <b>0</b> |

**Source:** Own calculations. Pathway A is based on pathway 2 from Tanneberger et al.(2021a).

The corresponding area of rewetted peatland is equal for the first decade with 58,500 ha p.a. (Appendix A1). In the first pathway A, the rewetted area remains almost constant from 2030 to 2049, in pathways B and C, the area in 2030 - 2039 is substantially higher compared to pathway A. Given the current rewetting pace of approximately 2,000 ha p.a. (Barthelmes et al., 2021), there is a vast area and CO<sub>2</sub> emission gap (Fig. 3). Maintaining the current rewetting pace until 2029 would cause a total CO<sub>2</sub> emission gap of 84.6 Mt CO<sub>2</sub> assuming only cropland is rewetted, to 148 Mt CO<sub>2</sub> assuming only grassland is rewetted. The total gap of rewetted area amounts to 565,160 ha from 2020 to 2029.

**Figure 3. Cumulative area gap and CO<sub>2</sub> emission gap between the current rate of rewetting and the rewetting pathways for agriculturally used peatlands in Germany in 2020-2029.**



Source: Own calculation based on Tanneberger et al. (2021a) and Barthelmes et al. (2021).

### 3.3. Politically justified budget

The financial packages of the German coal phase-out considered in our calculation have a total present value of 45.8 billion €. This includes compensation payments (4.35 billion €) (Bundestag, 2020a), funds for the Structural Development Act (40 billion €) (Bundestag, 2020b), and adjustment payments for employees (1.45 billion €) (Haywood et al., 2021). This politically determined budget is linked to a measure of successively reduced annual emissions of 110.1 Mt CO<sub>2</sub> in 2020 to 0 by 2038. Expressed as overall emission mitigation potential the pathway of coal phase-out mitigates 2,062 Mt CO<sub>2</sub> from 2020 to 2050 (Appendix A2).

Within the coal phase-out, to eliminate an annual source of one ton of CO<sub>2</sub> in 2020, we distribute a budget of 767 € whereas the budget decreases to 265 € in 2038 and to 37 € in 2049 (Appendix A3). The decline of the budget share over time is attributed to the decreasing mitigation contribution by eliminating an annual source of CO<sub>2</sub> and a discount rate ( $r$ ) of 2%.

The sum of mitigated cumulative tons of CO<sub>2</sub> along each pathway is the overall emission mitigation potential. We calculate totals of 616 Mt, 665 Mt and 715 Mt from 2020 to 2050 for pathways A, B and C, respectively (Table 4). Justified by the PESTLE analysis results (see 2.1), we apply  $pWTP_r^{coal}$  from coal phase-out as a blueprint to rewetting pathways A, B and C to calculate their politically justified budget  $B_{rm}^{rewetting}$ . With 16 billion € is  $B_{2\%,C}^{rewetting}$  the highest

for pathway C, which matches further with the highest overall emission mitigation potential among all three pathways (Table 4). For the results with a discount rate of 1 % and 3 %, please check Table 4 and Appendix A3.

**Table 4. Overall CO<sub>2</sub> emission mitigation potential and politically justified budget for the peatland drainage phase-out in Germany.**

|                                                          | Coal phase-out | Peatland drainage phase-out pathway A | Peatland drainage phase-out pathway B | Peatland drainage phase-out pathway C |
|----------------------------------------------------------|----------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Overall emission mitigation potential 2020 to 2050 in Mt | 2062.28        | 615.5                                 | 665.03                                | 714.6                                 |
| Politically justified budget in billion € (with r= 1 %)  | 45.8           | 13.74                                 | 14.82                                 | 15.94                                 |
| Politically justified budget in billion € (with r= 2 %)  | 45.8           | 13.81                                 | 14.87                                 | 16.0                                  |
| Politically justified budget in billion € (with r= 3 %)  | 45.8           | 13.9                                  | 14.93                                 | 16.07                                 |

**Source:** Own calculations. The budget for the coal phase-out is given by Haywood et al. (2021) as well as the respective laws (Bundestag, 2020a, 2020b). These include compensation payments, structural support, and adjustment funds for employees. The budget for the rewetting pathways A, B and C is based on our exploratory calculation. All budgets are expressed in present values for the year 2020, considering a 2 % discount rate (Appendix A3).

Further, the politically justified budget to eliminate an annual source of CO<sub>2</sub> emissions is applied to the specific emission reduction potential of 22.7 tons of CO<sub>2</sub> per ha for grassland and 29.7 tons of CO<sub>2</sub> per ha for cropland (Tanneberger et al., 2021a). It follows, that the politically justified budget to rewet one ha in 2020 ranges from 17,400 €/ha for grassland to 22,766 €/ha for cropland. Until 2049, it reduces to 830 €/ha for grassland and 1,086 €/ha for cropland (Table 5).

**Table 5. Politically justified budget to rewet one ha peatland under agricultural use in Germany.**

|                                                                     | 2020      |          | 2049      |          |
|---------------------------------------------------------------------|-----------|----------|-----------|----------|
|                                                                     | Grassland | Cropland | Grassland | Cropland |
| Politically justified budget to rewet one ha. In €/ha (with r= 1 %) | 16,471    | 21,550   | 916       | 1,199    |
| Politically justified budget to rewet one ha. In €/ha (with r= 2 %) | 17,400    | 22,766   | 830       | 1,086    |
| Politically justified budget to rewet one ha. In €/ha (with r= 3 %) | 18,419    | 24,099   | 748       | 979      |

**Source:** Own calculations. The politically justified budget to rewet one ha is calculated based on the specific emissions reduction potential for grassland (22.7 tons of CO<sub>2</sub> per ha) and cropland (29.7 tons CO<sub>2</sub> per ha) from Tanneberger et al.(2021a) and the calculated justified budget to eliminate an annual emission source (Annex C). The Budget is expressed in present values for the year 2020, considering the different discount rates (Appendix A3).

The results show a declining justified budget per ha over time. Note, that our results were initially calculated independently from potential costs (e.g., presented in Wichmann et al.(2022a)).

#### **4. Discussion**

The PESTLE approach underlines the far-reaching changes due to peatland rewetting along the six dimensions. Even though the comparison between peatland rewetting and the coal phase-out shows differences in each dimension, it emphasises that a peatland rewetting pathway in line with the Paris Agreement can be understood as a sociotechnical transition just like the termination of lignite-fired power generation. We understand drainage-based agriculture on peatlands as particularly evident to Geels (2011, p. 24) description of socio-technical transition. It is acknowledged that this socio-technical regime of drainage-based agriculture on peatlands represents a venue of established practices and associated regulations that initially stabilise the existing system. According to Loorbach et al. (2017), this entails path dependency and lock-in of the existing socio-technical system around this technology and practice.

This socio-technical transition which is, due to emission mitigation pressure, not initiated fast enough by market or economic forces calls for a governance perspective. Considering rewetting as a peatland drainage phase-out could open new perspectives and strategies as a bridging concept and governance approach (Trencher et al., 2023).

Since phase-out is a multidimensional approach in which a range of instruments are coordinated, the concept of broader change is well suited to initiate the transition (Geels et al., 2017; Johnstone and Hielscher, 2017; Markard et al., 2012; Rinscheid et al., 2021). The goal at the end of the phase-out is not simply exiting unsustainable practices and technologies, but adapting business practices and their legal framework over time to minimize and overcome economic and societal challenges as well as to incorporate the associated changes in the social, cultural and political dimensions, rather than making abrupt policy interventions (Rinscheid et al., 2021; Rosenbloom and Rinscheid, 2020).

A fundamental component of a politically driven phase-out is to determine and communicate the time horizon of the final exit (Heyen et al., 2017; Trencher et al., 2022b). Such a time horizon could in turn open-up the path dependencies and lock-in to drained peatland farming practice through deliberate termination with governmental pressure and further create planning reliability for stakeholders as it has been done in the case of the coal phase-out.

Since the current political strategy does not define a final date to phase-out peatland drainage, we present three rewetting pathways with different final exit dates, which lead to different levels

of ambition regarding the total CO<sub>2</sub> mitigation potential. In the development of our pathways, we have assumed a linear CO<sub>2</sub> decrease and have not considered the fact that there may be phases in which many areas are rewetted and others in which planning must first get underway, for example. Since the paper aims to present scenarios and pathways in line with the Paris Agreement rather than a feasibility study we hold on pathways with complete rewetting. The assumption to rewet all grassland and cropland is based on Tanneberger et al. (2021a). They presented the first German 1.5°C target pathway for organic soils and assumed a rewetting of all grassland and cropland until 2050. This assumption can be underlined by scientific articles which also address the necessity of rewetting of (almost) all drained peatlands to meet CO<sub>2</sub> and climate protection targets (Günther et al., 2020; Leifeld et al., 2019). The CO<sub>2</sub> reduction assumptions underlying the scenario are conservative compared to the national emissions factors from Tiemeyer et al. (2020). Considering the transferability of the pathways to other countries, it is important to note that the CO<sub>2</sub> emission factors before and after rewetting could differ due to variations in nutrient status and climate zones (IPCC, 2014). Additionally, emission factors can vary based on climate, soil, and hydrological conditions even within a single country. However, it is important to emphasise that regardless of the exact CO<sub>2</sub> emission factor, early investment in rewetting drained peatlands would build up a CO<sub>2</sub> reduction buffer. This, in turn, would increase the likelihood to meet the overall CO<sub>2</sub> reduction requirements of the rewetting pathways.

Since drained peatlands are an annual emission source, concerning the carbon budget and the objective of achieving carbon neutrality the timing of rewetting is also important (cf., Günther et al., 2020). The calculated CO<sub>2</sub> emission gap underscores the critical significance of the timing and pace of rewetting (Günther et al., 2020; Chen, 2021; IPCC, 2021b;). In case of future land use change inducing recurrence of peatland drainage after rewetting, emissions would still have been avoided in the wet peatland period, entailing reduced atmospheric carbon accumulation. To close the emission gap and buffer the multidimensional effects of the peatland drainage phase-out to be sustainable and just, a budget for financial assistance is necessary (Kanger et al., 2020; Spencer et al., 2018). The coal phase-out has demonstrated that there is a political willingness to pay for a just transition to reduce emissions in a socially acceptable manner. The politically justified budget derived from the coal phase-out suggests a financial volume, which is beyond the funding currently allocated to peatland rewetting. Our results suggest that in the early 2020s around 1.0 billion € p.a. could be politically justified for peatland rewetting to meet climate goals (Appendix A3 - Table A3.2 to A3.4). Currently, the spending at the federal level for peatland rewetting and protection included in the German Action Programme for Natural

Climate Protection (BMUV, 2022a), which is supposed to represent the main financial budget for national peatland protection in Germany (Deutscher Bundestag, 2023), shows a considerably lower budget (UNEP, 2022; German federal budget plan, 2023, 2024).

Our calculated politically justified budget should be interpreted as an integrated financial envelope. Any division into packages should follow the specific logic and necessities of peatland rewetting. The package design for the coal phase-out includes structural aids, compensation payments, labour market policies, decommissioning of CO<sub>2</sub> certificates, and compensation for electricity costs. Drained peatlands are concentrated in a few federal states which would justify a trans-regional financial compensation (Isermeyer et al., 2019) similar to the structural aid package. However, peatlands are more decentralised than opencast mining areas, and the structure of farms is more heterogeneous and small- to medium-sized compared to the corporate structure of the large lignite power companies. Furthermore, the rewetting of peatlands currently needs protected permission procedures. The phase-out approach states that for a sustainable transition, the choice of instruments needs a holistic policy design, using all types of instruments beyond the existing schemes. Chen et al. (2023) suggest a combination of “stick and carrot” policies, which includes incentive-based policies and regulations. As Rinscheid et al. (2021) state, public policy instruments like subsidy removal, bans, taxation, and performance standards are instruments to shape a phase-out which are currently beyond consideration for peatland rewetting. The PESTLE approach with the comparison to the coal phase-out points out, that peatland drainage phase-out requires a legally binding strategy with a legal and administrative framework. Concerning the coal phase-out, a peatland drainage phase-out law could also be considered to anchor the aim and to clarify the long-term strategy, measures, and instruments. To align agricultural policy with climate objectives and maintain a wider array of potential policy instruments, it’s purposeful to reconsider the principle of unlimited voluntariness in communication. The societal support for a phase-out is stronger for the lignite phase-out than for the peatland drainage phase-out. These differences to the coal phase-out could offer starting points to govern a phase-out in a socially acceptable way. For example, promoting paludiculture and downstream value chains as complements to peatland drainage termination is economically viable since it could directly contribute to reducing farmers’ opportunity costs and could also be beneficial strategies to increase societal acceptance. Enhancing societal awareness and understanding of peatland drainage issues also supports social acceptance.

If the coal phase-out is used as a blueprint to initiate phase-out in other sectors, it is also important to learn from its failures and shortcomings. For example, by convening a commission,

the government needs to ensure and communicate in advance how the recommendations will be used. Moreover, compensation payments should be based on economic evidence and aligned with climate goals (Heilmann and Popp, 2020). The literature offers studies to classify the coal phase-out in the theoretical context of sustainability transition (Koretsky et al., 2022; Leipprand and Flachsland, 2018) and transition governance (Spencer et al., 2018) and also in international comparison (Rinscheid et al., 2021; Gürtler et al., 2021; Brauers et al., 2020). In this regard, our paper creates added value by comparing peatland rewetting to the coal phase-out and empathising it as a socio-technical transition - governed as peatland drainage phase-out. Further research and an international comparison of peatland rewetting as a sustainable transition could be beneficial for the literature.

This paper shows the complexity and dimension to govern the transition towards peatland rewetting as a socially acceptable pathway and to apply the phase-out approach using the example of Germany. Due to insufficient data, region-specific conditions, and a range of case specific cost factors, it is challenging to accurately assess the costs associated with rewetting. We interpreted the set budget for the coal phase-out as pWTP and derived a politically justified budget which does not quantify the total costs of implementing the rewetting pathway. We show that abatement costs (construction, planning, compensation, structural programmes etc.) for early rewetted peatlands are more likely to be in line with the (over time decreasing) pWTP and the corresponding justified budget to rewet one hectare peatland than for later ones. Further research as well as data collection and analysis are needed to specify the real costs of implementing a rewetting pathway. A few studies quantify opportunity costs for Germany (cf., Röder and Grützmacher, 2012; Schaller, 2014; Krimly et al., 2016; Domke, 2023), socio-economic effects of large-scale rewetting in peatland-rich regions also need to be further investigated, i.e. regarding downstream jobs, need of (public) financial investments for economic diversification in local communities (cf. Banerjee and Schuitema, 2022). or technical investments for water retention at catchment area scale. Further, the derived politically justified budget is derived by the CO<sub>2</sub> mitigation potential and not in relation to the affected workforce or share of GDP, for example. The GDP per Capita in Table 1 gives insights into the economic strength and welfare. Peatlands occur in almost all EU Member States with a concentration in north-western, Nordic and eastern European countries, covering an area of circa 350,000 km<sup>2</sup>. More than 50 % of this area is degraded by the effects of drainage and used for agriculture, forestry and peat extraction (Tanneberger et al., 2021b). The EU is the second largest emitter of GHG from drained peatlands globally (220 Mt CO<sub>2</sub>e/year = 15 % of total global peatland emissions), which is equivalent to circa 5 % of the official EU greenhouse gas emissions. While

our primary focus is on Germany, the conceptual considerations may also apply to other countries with extensive drained peatlands under agricultural use. However, this approach could also be applied to phasing out forestry on drained peatlands or peat extraction, making it relevant for countries with significant forest areas or peat extraction activities. Additionally, our approach could be of interest to others analysing phase-outs with allocated budgets for a socially acceptable transition, especially regarding CO<sub>2</sub> mitigation potential from peatland rewetting. However, varying socio-economic conditions across countries can significantly impact the feasibility of these pathways. Further, this approach could also offer insights into agricultural governance at the European Union level, as peatland rewetting trajectories interact with EU agriculture and climate policies.

## 5. Conclusion

Applying coal phase-out as a blueprint for the transition of peatland rewetting has some merits and caveats. Peatland rewetting can contribute significantly to carbon neutrality and emission mitigation goals within the LULUCF sector, just as the coal phase-out does in the energy sector. Our results show that coal phase-out and peatland phase-out have many similarities but some striking differences along the PESTLE dimensions. Furthermore, PESTLE dimensions and the comparison to the coal phase-out underline the understanding of peatland rewetting as a socio-technical transition. Most notably the two processes differ in the number of affected stakeholders and enterprises in the economic dimension. As with the coal phase-out, our results suggest that rewetting has significant implications for multiple dimensions in the sector. Therefore, rewetting to be sustainable and in-line with the agreed climate targets calls for governmental intervention and a guided multilevel perspective on this transition.

As we argued that peatland rewetting is necessary to meet internationally agreed targets, our results suggest that current rates of rewetting cannot meet the medium-term targets of the rewetting pathways, which is in line with the targets of the Paris Agreement. Keeping the current pace of rewetting would create an area gap of 565,160 ha and a resulting CO<sub>2</sub> emission gap of 84.6–148 Mt CO<sub>2</sub> by 2029.

Using the coal phase-out timeline and budget, we derive a budget for peatland drainage phase-out for three different pathways until 2040, 2045 and 2050. The resulting budget is 13.8–16 billion € for the rewetting pathways with a discount rate of 2 %.

As discussed above, this budget was derived from the coal phase-out and should be understood as a financial envelope to cover the costs of a social and just transition. The coal phase-out is not a one-to-one blueprint for the peatland drainage phase-out and additional costs might occur.

## CHAPTER 3

Therefore, further research and indications about the interlinkage between economic strength, emissions from drained peatlands, area to be rewetted and the politically justified budget is needed.

## 6. Appendices

### A1

**Table A1.1. Necessary area of agricultural drained peatland in Germany that must be rewetted annually to achieve the CO<sub>2</sub> reductions in Table 3.**

| Area p.a.<br>in ha | Pathway A*    |               |               |               | Pathway B*    |               |               | Pathway C*    |               |
|--------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
|                    | 2020-29       | 2030-39       | 2040-44       | 2045-49       | 2020-29       | 2030-39       | 2040-44       | 2020-29       | 2030-39       |
| Grassland          | 20,132        | 43,700        | 43,612        | 43,700        | 20,132        | 58,238        | 29,119        | 20,132        | 87,357        |
| Cropland           | 38,383        | –             | –             | –             | 38,383        | –             | –             | 38,383        | –             |
| <b>Total</b>       | <b>58,516</b> | <b>43,700</b> | <b>43,612</b> | <b>43,700</b> | <b>58,516</b> | <b>58,238</b> | <b>29,119</b> | <b>58,516</b> | <b>87,357</b> |

**Source:** Own calculations; \* Calculations based on the emission reduction potential by Tanneberger et al. (2021) (i.e., 22.7 CO<sub>2</sub> per ha for grassland and 29.7 CO<sub>2</sub> per ha for cropland).

## A2

**Table A2.1. CO<sub>2</sub> mitigation potential through the planned shutdown of lignite-fired power plants according to Annex II of the CPOA 2020.**

| Mining area    | Plant                      | Shutdown     | Annual CO <sub>2</sub> -Emissions in Mt | Emission Mitigation Potential in Mt (cumulated until 2050) |
|----------------|----------------------------|--------------|-----------------------------------------|------------------------------------------------------------|
| Rhineland      | Niederaußem C              | 31.12.2021   | 2.2                                     | 63.8                                                       |
|                | Niederaußem D              | 31.12.2020   | 2.1                                     | 63                                                         |
|                | Niederaußem G <sup>1</sup> | 31.12.2029   | 3.6                                     | 75.6                                                       |
|                | Niederaußem H <sup>2</sup> | 31.12.2029   | 3.8                                     | 79.8                                                       |
|                | Niederaußem K              | 31.12.2038   | 6.6                                     | 79.2                                                       |
|                | Neurath A                  | 01.04.2022   | 2.1                                     | 60.375                                                     |
|                | Neurath B                  | 31.12.2021   | 1.7                                     | 49.3                                                       |
|                | Neurath D                  | 31.12.2022   | 2                                       | 56                                                         |
|                | Neurath E                  | 31.12.2022   | 3.7                                     | 103.6                                                      |
|                | Neurath F                  | 31.12.2038   | 5.5                                     | 66                                                         |
|                | Neurath G                  | 31.12.2038   | 6.5                                     | 78                                                         |
|                | Weisweiler E <sup>3</sup>  | 31.12.2021   | 2.4                                     | 69.6                                                       |
|                | Weisweiler F <sup>3</sup>  | 01.01.2025   | 1.4                                     | 36.4                                                       |
|                | Weisweiler G <sup>4</sup>  | 01.04.2028   | 3.9                                     | 88.725                                                     |
|                | Weisweiler H               | 01.04.2029   | 5.3                                     | 115.275                                                    |
|                | Frechen                    | 31.12.2022   | 0.8                                     | 22.4                                                       |
| Lusatia        | Jänschwalde A <sup>5</sup> | 31.12.2025   | 4.2                                     | 105                                                        |
|                | Jänschwalde B              | 31.12.2027   | 4.1                                     | 94.3                                                       |
|                | Jänschwalde C              | 31.12.2028   | 3.1                                     | 68.2                                                       |
|                | Jänschwalde D              | 31.12.2028   | 3.7                                     | 81.4                                                       |
|                | Boxberg N                  | 31.12.2029   | 3.3                                     | 69.3                                                       |
|                | Boxberg P                  | 31.12.2029   | 4.3                                     | 90.3                                                       |
|                | Boxberg R                  | 31.12.2038   | 4.1                                     | 49.2                                                       |
|                | Boxberg Q                  | 31.12.2038   | 6.8                                     | 81.6                                                       |
|                | Schwarze Pumpe A           | 31.12.2038   | 5.5                                     | 66                                                         |
|                | Schwarze Pumpe B           | 31.12.2038   | 4.9                                     | 58.8                                                       |
| Central German | Schopkau A                 | 31.12.2034   | 2.1                                     | 33.6                                                       |
|                | Schopkau B                 | 31.12.2034   | 1.5                                     | 24                                                         |
|                | Lippendorf R               | 31.12.2035   | 4.6                                     | 69                                                         |
|                | Lippendorf S               | 31.12.2035   | 4.3                                     | 64.5                                                       |
|                |                            | <b>Total</b> | <b>110.1</b>                            | <b>2062.28</b>                                             |

Source: Bundestag (2020a) – Anlage 2: Stilllegungszeitpunkte Braunkohleanlagen; Öko-Institut (2020).

<sup>1</sup> Right to choose between Niederaußem G and H.

<sup>2</sup> Right to choose between Niederaußem G and H + time stretched shutdown: 31.12.2033.

<sup>3</sup> Right to choose between Weisweiler E and F.

<sup>4</sup> Right to choose between Weisweiler G and H.

<sup>5</sup> Time stretched shutdown: 31.12.2028.

A3

Table A3.1. Lignite: Calculations linked to Section 3.3

| 1        | 2                                                                 | 3                                                   | 4                      | 5                                                                                                                 | 6                      | 7                                                                                                                 | 8                      | 9                                                                                                                 |
|----------|-------------------------------------------------------------------|-----------------------------------------------------|------------------------|-------------------------------------------------------------------------------------------------------------------|------------------------|-------------------------------------------------------------------------------------------------------------------|------------------------|-------------------------------------------------------------------------------------------------------------------|
| Year     | Elimination of an annual CO <sub>2</sub> -emission source (in Mt) | Total mitigated emission potential compared to 2020 | $pWTP_r^{coal} * DF_t$ | Justified Budget to eliminate an annual CO <sub>2</sub> -emissions source in t<br>=<br>$jb_{rt}^{annual\ source}$ | $pWTP_r^{coal} * DF_t$ | Justified Budget to eliminate an annual CO <sub>2</sub> -emissions source in t<br>=<br>$jb_{rt}^{annual\ source}$ | $pWTP_r^{coal} * DF_t$ | Justified Budget to eliminate an annual CO <sub>2</sub> -emissions source in t<br>=<br>$jb_{rt}^{annual\ source}$ |
| t        | $\Delta X_{it}$                                                   | $\sum_t^T x_{it}$                                   | r=1%                   | r=2%                                                                                                              | r=2%                   | r=3%                                                                                                              | r=3%                   | r=3%                                                                                                              |
| 2020     | 0.00                                                              | 0.00                                                | 27.07                  | 725.59                                                                                                            | 32.78                  | 766.52                                                                                                            | 39.41                  | 811.41                                                                                                            |
| 2021     | 2.10                                                              | 2.10                                                | 26.80                  | 698.52                                                                                                            | 32.13                  | 733.75                                                                                                            | 38.26                  | 771.99                                                                                                            |
| 2022     | 7.88                                                              | 9.97                                                | 26.54                  | 671.71                                                                                                            | 31.50                  | 701.61                                                                                                            | 37.15                  | 733.73                                                                                                            |
| 2023     | 7.02                                                              | 17.00                                               | 26.28                  | 645.17                                                                                                            | 30.89                  | 670.11                                                                                                            | 36.07                  | 696.58                                                                                                            |
| 2024     | 0.00                                                              | 17.00                                               | 26.02                  | 618.90                                                                                                            | 30.28                  | 639.22                                                                                                            | 35.02                  | 660.52                                                                                                            |
| 2025     | 1.40                                                              | 18.40                                               | 25.76                  | 592.88                                                                                                            | 29.69                  | 608.94                                                                                                            | 34.00                  | 625.50                                                                                                            |
| 2026     | 4.20                                                              | 22.60                                               | 25.50                  | 567.12                                                                                                            | 29.10                  | 579.26                                                                                                            | 33.01                  | 591.50                                                                                                            |
| 2027     | 0.00                                                              | 22.60                                               | 25.25                  | 541.62                                                                                                            | 28.53                  | 550.15                                                                                                            | 32.04                  | 558.50                                                                                                            |
| 2028     | 7.03                                                              | 29.63                                               | 25.00                  | 516.37                                                                                                            | 27.97                  | 521.62                                                                                                            | 31.11                  | 526.45                                                                                                            |
| 2029     | 11.75                                                             | 41.38                                               | 24.75                  | 491.36                                                                                                            | 27.43                  | 493.64                                                                                                            | 30.21                  | 495.34                                                                                                            |
| 2030     | 16.33                                                             | 57.70                                               | 24.51                  | 466.61                                                                                                            | 26.89                  | 466.22                                                                                                            | 29.33                  | 465.14                                                                                                            |
| 2031     | 0.00                                                              | 57.70                                               | 24.27                  | 442.10                                                                                                            | 26.36                  | 439.33                                                                                                            | 28.47                  | 435.81                                                                                                            |
| 2032     | 0.00                                                              | 57.70                                               | 24.03                  | 417.84                                                                                                            | 25.84                  | 412.97                                                                                                            | 27.64                  | 407.34                                                                                                            |
| 2033     | 0.00                                                              | 57.70                                               | 23.79                  | 393.81                                                                                                            | 25.34                  | 387.13                                                                                                            | 26.84                  | 379.70                                                                                                            |
| 2034     | 0.00                                                              | 57.70                                               | 23.55                  | 370.02                                                                                                            | 24.84                  | 361.79                                                                                                            | 26.06                  | 352.86                                                                                                            |
| 2035     | 3.60                                                              | 61.30                                               | 23.32                  | 346.47                                                                                                            | 24.35                  | 336.95                                                                                                            | 25.30                  | 326.81                                                                                                            |
| 2036     | 8.90                                                              | 70.20                                               | 23.09                  | 323.15                                                                                                            | 23.88                  | 312.59                                                                                                            | 24.56                  | 301.51                                                                                                            |
| 2037     | 0.00                                                              | 70.20                                               | 22.86                  | 300.06                                                                                                            | 23.41                  | 288.72                                                                                                            | 23.84                  | 276.95                                                                                                            |
| 2038     | 0.00                                                              | 70.20                                               | 22.63                  | 277.20                                                                                                            | 22.95                  | 265.31                                                                                                            | 23.15                  | 253.11                                                                                                            |
| 2039     | 39.90                                                             | 110.10                                              | 22.41                  | 254.57                                                                                                            | 22.50                  | 242.36                                                                                                            | 22.48                  | 229.96                                                                                                            |
| 2040     | 0.00                                                              | 110.10                                              | 22.19                  | 232.16                                                                                                            | 22.06                  | 219.86                                                                                                            | 21.82                  | 207.48                                                                                                            |
| 2041     | 0.00                                                              | 110.10                                              | 21.89                  | 209.97                                                                                                            | 21.48                  | 197.81                                                                                                            | 20.98                  | 185.66                                                                                                            |
| 2042     | 0.00                                                              | 110.10                                              | 21.65                  | 188.08                                                                                                            | 21.02                  | 176.32                                                                                                            | 20.30                  | 164.68                                                                                                            |
| 2043     | 0.00                                                              | 110.10                                              | 21.53                  | 166.42                                                                                                            | 20.79                  | 155.31                                                                                                            | 19.97                  | 144.38                                                                                                            |
| 2044     | 0.00                                                              | 110.10                                              | 21.32                  | 144.89                                                                                                            | 20.38                  | 134.52                                                                                                            | 19.39                  | 124.41                                                                                                            |
| 2045     | 0.00                                                              | 110.10                                              | 21.11                  | 123.57                                                                                                            | 19.98                  | 114.14                                                                                                            | 18.82                  | 105.03                                                                                                            |
| 2046     | 0.00                                                              | 110.10                                              | 20.90                  | 102.46                                                                                                            | 19.59                  | 94.17                                                                                                             | 18.27                  | 86.20                                                                                                             |
| 2047     | 0.00                                                              | 110.10                                              | 20.69                  | 81.56                                                                                                             | 19.20                  | 74.58                                                                                                             | 17.74                  | 67.93                                                                                                             |
| 2048     | 0.00                                                              | 110.10                                              | 20.49                  | 60.86                                                                                                             | 18.83                  | 55.38                                                                                                             | 17.23                  | 50.19                                                                                                             |
| 2049     | 0.00                                                              | 110.10                                              | 20.29                  | 40.37                                                                                                             | 18.46                  | 36.55                                                                                                             | 16.72                  | 32.96                                                                                                             |
| 2050     | 0.00                                                              | 110.10                                              | 20.09                  | 20.09                                                                                                             | 18.09                  | 18.09                                                                                                             | 16.24                  | 16.24                                                                                                             |
| $\Sigma$ | $\Sigma_t^T \Delta X_{it} = 110.1$                                | $Z = 2062.28$                                       |                        |                                                                                                                   |                        |                                                                                                                   |                        |                                                                                                                   |

**Source:** Own calculations. Based on the data from Öko-Institut (2020) for CO<sub>2</sub> emissions from lignite-fired power plants as well as the date of the shutdown and the provided budget for the coal phase-out (Bundestag, 2020a, 2020b; Haywood et al., 2021). The table shows the CO<sub>2</sub>-emission mitigation potential of the coal phase-out and the derived political willingness to pay and politically justified budget to eliminate an annual CO<sub>2</sub>- emission source in present values of the year 2020 with discount rates of 1 %; 2 % and 3 % respectively. **Note:** **Column 1** shows the time horizon with  $t_0 = 2020, \dots, t, \dots, T = 2050$ . **Column 2** is the quantity and point in time at which an annual CO<sub>2</sub> emission source is eliminated, **Column 3** shows the cumulative emissions saving from lignite, which represents the necessary elimination of annual CO<sub>2</sub>-emission sources summed up from 2020 to t along the rewetting pathway. It follows that the sum of all values in column 3 from 2020 to 2050 gives Z and quantifies the overall CO<sub>2</sub> emission mitigation potential by the time 2050 for the 2020 adopted coal phase-out. **Column 4** shows the discounted political willingness to pay to mitigate one cumulative ton of CO<sub>2</sub> at time t. Since  $DF_t$  and  $\Delta X_{it}$  is known and the total Budget of 48.8 billion € is set, we can determine the  $pWTP_r^{coal}$  with equation (5) from section 4.3.2. **Column 5** shows the politically justified budget to eliminate an annual source of one ton of CO<sub>2</sub> in time t. This is calculated by summing up the discounted  $pWTP_r^{coal}$  from the point of elimination t until T. The values for the discounted  $pWTP_r^{coal}$  and  $jb_{rt}^{annual\ source}$ . **Column 5 to 9** vary due to the set discount rate of 1 %, 2 % and 3 %.

**Table A3.2. Pathway A: Calculations linked to Section 3.3**

| 1        | 2                                                           | 3                                                                 | 4                                                                                          | 5                                                                                                                 | 6                                                                 | 7                                                                                                                 | 8                                                                 | 9                                                                                                                 | 10                                                                             |
|----------|-------------------------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Year     | Annual emissions from agriculturally used peatlands (in Mt) | Elimination of an annual CO <sub>2</sub> -emission source (in Mt) | Elimination of an annual CO <sub>2</sub> -emission source summed up from 2020 to t (in Mt) | Justified Budget to eliminate an annual CO <sub>2</sub> -emissions source in t = $jb_{rt}^{annual source}$ (in €) | Annual share of total Budget $b_{rtm}^{rewetting}$ (in Million €) | Justified Budget to eliminate an annual CO <sub>2</sub> -emissions source in t = $jb_{rt}^{annual source}$ (in €) | Annual share of total Budget $b_{rtm}^{rewetting}$ (in Million €) | Justified Budget to eliminate an annual CO <sub>2</sub> -emissions source in t = $jb_{rt}^{annual source}$ (in €) | Annual share of total Budget In million € $b_{rtm}^{rewetting}$ (in Million €) |
| t        | $X_{it}$                                                    | $\Delta X_{itm}^{rewetting}$                                      | $\sum_t^T X_{it}$                                                                          | r=1 %                                                                                                             | r=2 %                                                             | r=3 %                                                                                                             |                                                                   |                                                                                                                   |                                                                                |
| 2020     | 35.80                                                       | 0.00                                                              | 0.00                                                                                       | 725.59                                                                                                            | 0.00                                                              | 766.52                                                                                                            | 0.00                                                              | 811.41                                                                                                            | 0.00                                                                           |
| 2021     | 34.20                                                       | 1.60                                                              | 1.60                                                                                       | 698.52                                                                                                            | 1115.53                                                           | 733.75                                                                                                            | 1171.79                                                           | 771.99                                                                                                            | 1232.87                                                                        |
| 2022     | 32.61                                                       | 1.60                                                              | 3.19                                                                                       | 671.71                                                                                                            | 1072.72                                                           | 701.61                                                                                                            | 1120.48                                                           | 733.73                                                                                                            | 1171.77                                                                        |
| 2023     | 31.01                                                       | 1.60                                                              | 4.79                                                                                       | 645.17                                                                                                            | 1030.34                                                           | 670.11                                                                                                            | 1070.16                                                           | 696.58                                                                                                            | 1112.44                                                                        |
| 2024     | 29.41                                                       | 1.60                                                              | 6.39                                                                                       | 618.90                                                                                                            | 988.38                                                            | 639.22                                                                                                            | 1020.84                                                           | 660.52                                                                                                            | 1054.84                                                                        |
| 2025     | 27.82                                                       | 1.60                                                              | 7.99                                                                                       | 592.88                                                                                                            | 946.83                                                            | 608.94                                                                                                            | 972.48                                                            | 625.50                                                                                                            | 998.92                                                                         |
| 2026     | 26.22                                                       | 1.60                                                              | 9.58                                                                                       | 567.12                                                                                                            | 905.69                                                            | 579.26                                                                                                            | 925.07                                                            | 591.50                                                                                                            | 944.63                                                                         |
| 2027     | 24.62                                                       | 1.60                                                              | 11.18                                                                                      | 541.62                                                                                                            | 864.96                                                            | 550.15                                                                                                            | 878.59                                                            | 558.50                                                                                                            | 891.92                                                                         |
| 2028     | 23.02                                                       | 1.60                                                              | 12.78                                                                                      | 516.37                                                                                                            | 824.64                                                            | 521.62                                                                                                            | 833.02                                                            | 526.45                                                                                                            | 840.75                                                                         |
| 2029     | 21.43                                                       | 1.60                                                              | 14.37                                                                                      | 491.36                                                                                                            | 784.71                                                            | 493.64                                                                                                            | 788.35                                                            | 495.34                                                                                                            | 791.06                                                                         |
| 2030     | 19.83                                                       | 1.60                                                              | 15.97                                                                                      | 466.61                                                                                                            | 745.18                                                            | 466.22                                                                                                            | 744.55                                                            | 465.14                                                                                                            | 742.82                                                                         |
| 2031     | 18.84                                                       | 0.99                                                              | 16.96                                                                                      | 442.10                                                                                                            | 438.57                                                            | 439.33                                                                                                            | 435.82                                                            | 435.81                                                                                                            | 432.33                                                                         |
| 2032     | 17.85                                                       | 0.99                                                              | 17.95                                                                                      | 417.84                                                                                                            | 414.49                                                            | 412.97                                                                                                            | 409.67                                                            | 407.34                                                                                                            | 404.08                                                                         |
| 2033     | 16.85                                                       | 0.99                                                              | 18.95                                                                                      | 393.81                                                                                                            | 390.66                                                            | 387.13                                                                                                            | 384.03                                                            | 379.70                                                                                                            | 376.66                                                                         |
| 2034     | 15.86                                                       | 0.99                                                              | 19.94                                                                                      | 370.02                                                                                                            | 367.06                                                            | 361.79                                                                                                            | 358.89                                                            | 352.86                                                                                                            | 350.04                                                                         |
| 2035     | 14.87                                                       | 0.99                                                              | 20.93                                                                                      | 346.47                                                                                                            | 343.70                                                            | 336.95                                                                                                            | 334.25                                                            | 326.81                                                                                                            | 324.19                                                                         |
| 2036     | 13.88                                                       | 0.99                                                              | 21.92                                                                                      | 323.15                                                                                                            | 320.57                                                            | 312.59                                                                                                            | 310.09                                                            | 301.51                                                                                                            | 299.10                                                                         |
| 2037     | 12.89                                                       | 0.99                                                              | 22.91                                                                                      | 300.06                                                                                                            | 297.66                                                            | 288.72                                                                                                            | 286.41                                                            | 276.95                                                                                                            | 274.73                                                                         |
| 2038     | 11.89                                                       | 0.99                                                              | 23.91                                                                                      | 277.20                                                                                                            | 274.99                                                            | 265.31                                                                                                            | 263.19                                                            | 253.11                                                                                                            | 251.08                                                                         |
| 2039     | 10.90                                                       | 0.99                                                              | 24.90                                                                                      | 254.57                                                                                                            | 252.53                                                            | 242.36                                                                                                            | 240.42                                                            | 229.96                                                                                                            | 228.12                                                                         |
| 2040     | 9.91                                                        | 0.99                                                              | 25.89                                                                                      | 232.16                                                                                                            | 230.30                                                            | 219.86                                                                                                            | 218.10                                                            | 207.48                                                                                                            | 205.82                                                                         |
| 2041     | 8.92                                                        | 0.99                                                              | 26.88                                                                                      | 209.97                                                                                                            | 208.08                                                            | 197.81                                                                                                            | 196.03                                                            | 185.66                                                                                                            | 183.99                                                                         |
| 2042     | 7.93                                                        | 0.99                                                              | 27.87                                                                                      | 188.08                                                                                                            | 186.39                                                            | 176.32                                                                                                            | 174.74                                                            | 164.68                                                                                                            | 163.20                                                                         |
| 2043     | 6.94                                                        | 0.99                                                              | 28.86                                                                                      | 166.42                                                                                                            | 164.93                                                            | 155.31                                                                                                            | 153.91                                                            | 144.38                                                                                                            | 143.08                                                                         |
| 2044     | 5.95                                                        | 0.99                                                              | 29.85                                                                                      | 144.89                                                                                                            | 143.59                                                            | 134.52                                                                                                            | 133.31                                                            | 124.41                                                                                                            | 123.29                                                                         |
| 2045     | 4.96                                                        | 0.99                                                              | 30.85                                                                                      | 123.57                                                                                                            | 122.46                                                            | 114.14                                                                                                            | 113.12                                                            | 105.03                                                                                                            | 104.08                                                                         |
| 2046     | 3.96                                                        | 0.99                                                              | 31.84                                                                                      | 102.46                                                                                                            | 101.54                                                            | 94.17                                                                                                             | 93.32                                                             | 86.20                                                                                                             | 85.43                                                                          |
| 2047     | 2.97                                                        | 0.99                                                              | 32.83                                                                                      | 81.56                                                                                                             | 80.82                                                             | 74.58                                                                                                             | 73.91                                                             | 67.93                                                                                                             | 67.32                                                                          |
| 2048     | 1.98                                                        | 0.99                                                              | 33.82                                                                                      | 60.86                                                                                                             | 60.31                                                             | 55.38                                                                                                             | 54.88                                                             | 50.19                                                                                                             | 49.73                                                                          |
| 2049     | 0.99                                                        | 0.99                                                              | 34.81                                                                                      | 40.37                                                                                                             | 40.01                                                             | 36.55                                                                                                             | 36.22                                                             | 32.96                                                                                                             | 32.66                                                                          |
| 2050     | 0.00                                                        | 0.99                                                              | 35.80                                                                                      | 20.09                                                                                                             | 19.91                                                             | 18.09                                                                                                             | 17.93                                                             | 16.24                                                                                                             | 16.09                                                                          |
| $\Sigma$ |                                                             |                                                                   | Z= 615.5                                                                                   |                                                                                                                   | $B_{1\%,A}^{rewetting}$ 13,737.5                                  |                                                                                                                   | $B_{2\%,A}^{rewetting}$ 13,813.6                                  |                                                                                                                   | $B_{3\%,A}^{rewetting}$ 13,897.1                                               |

Source: Own calculations.

Note: **Column 1** shows time horizon with  $t_0 = 2020, \dots, t, \dots, T = 2050$ . **Column 2** shows the remaining annual CO<sub>2</sub> emissions along the rewetting pathway. While **column 3** shows the quantity and point in time at which an annual CO<sub>2</sub> emission source is eliminated. **Column 4** shows the necessary elimination of annual CO<sub>2</sub>-emission sources summed up from 2020 to t along the rewetting pathway. It follows that the sum of all values in **column 4** from 2020 to 2050 gives Z and quantifies the overall CO<sub>2</sub> emission mitigation potential of the pathway by the time 2050. **Column 5** shows the politically justified budget to eliminate an annual source of one ton of CO<sub>2</sub> in time t based on the coal phase-out (see column 5 in Table 7). Due to the set discount rate of 1 %, 2 % and 3 %,  $jb_{rt}^{annual source}$  varies in **column 5, 7 and 9**. **Columns 6, 8 and 10** show the politically justified budget per year regarding the corresponding quantity of eliminated annual CO<sub>2</sub> emission sources in that year. Cumulating the annual budget from 2020 to 2050 results in a total justified political budget  $B_{rm}^{rewetting}$ .

**Table A3.3. Pathway B: Calculations linked to Section 3.3**

| 1        | 2                                                         | 3                                                              | 4                                                                                       | 5                                                                                                                 | 6                                                                                                                                     | 7                                                                                                                         | 8                                                                                                                                     | 9                                                                                                                 | 10                                                                                                                                    |
|----------|-----------------------------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| Year     | Annual emissions from agricultural peatlands used (in Mt) | Elimination of annual CO <sub>2</sub> -emission source (in Mt) | Elimination of annual CO <sub>2</sub> -emission source summed up from 2020 to t (in Mt) | Justified Budget to eliminate an annual CO <sub>2</sub> -emissions source in t = $jb_{rt}^{annual source}$ (in €) | Annual share of total Budget to eliminate an annual CO <sub>2</sub> -emissions source in t = $jb_{rt}^{annual source}$ (in Million €) | Justified Budget to eliminate an annual CO <sub>2</sub> -emissions source in t = $jb_{rt}^{annual source}$ (in Million €) | Annual share of total Budget to eliminate an annual CO <sub>2</sub> -emissions source in t = $jb_{rt}^{annual source}$ (in Million €) | Justified Budget to eliminate an annual CO <sub>2</sub> -emissions source in t = $jb_{rt}^{annual source}$ (in €) | Annual share of total Budget to eliminate an annual CO <sub>2</sub> -emissions source in t = $jb_{rt}^{annual source}$ (in Million €) |
| t        | $X_{it}$                                                  | $\Delta X_{itm}^{rewetting}$                                   | $\sum_t^T x_{it}$                                                                       | r=1 %                                                                                                             | r=2 %                                                                                                                                 | r=3 %                                                                                                                     |                                                                                                                                       |                                                                                                                   |                                                                                                                                       |
| 2020     | 35.80                                                     | 0.00                                                           | 0.00                                                                                    | 725.59                                                                                                            | 0.00                                                                                                                                  | 766.52                                                                                                                    | 0.00                                                                                                                                  | 811.41                                                                                                            | 0.00                                                                                                                                  |
| 2021     | 34.20                                                     | 1.60                                                           | 1.60                                                                                    | 698.52                                                                                                            | 1115.53                                                                                                                               | 733.75                                                                                                                    | 1171.79                                                                                                                               | 771.99                                                                                                            | 1232.87                                                                                                                               |
| 2022     | 32.61                                                     | 1.60                                                           | 3.19                                                                                    | 671.71                                                                                                            | 1072.72                                                                                                                               | 701.61                                                                                                                    | 1120.48                                                                                                                               | 733.73                                                                                                            | 1171.77                                                                                                                               |
| 2023     | 31.01                                                     | 1.60                                                           | 4.79                                                                                    | 645.17                                                                                                            | 1030.34                                                                                                                               | 670.11                                                                                                                    | 1070.16                                                                                                                               | 696.58                                                                                                            | 1112.44                                                                                                                               |
| 2024     | 29.41                                                     | 1.60                                                           | 6.39                                                                                    | 618.90                                                                                                            | 988.38                                                                                                                                | 639.22                                                                                                                    | 1020.84                                                                                                                               | 660.52                                                                                                            | 1054.84                                                                                                                               |
| 2025     | 27.82                                                     | 1.60                                                           | 7.99                                                                                    | 592.88                                                                                                            | 946.83                                                                                                                                | 608.94                                                                                                                    | 972.48                                                                                                                                | 625.50                                                                                                            | 998.92                                                                                                                                |
| 2026     | 26.22                                                     | 1.60                                                           | 9.58                                                                                    | 567.12                                                                                                            | 905.69                                                                                                                                | 579.26                                                                                                                    | 925.07                                                                                                                                | 591.50                                                                                                            | 944.63                                                                                                                                |
| 2027     | 24.62                                                     | 1.60                                                           | 11.18                                                                                   | 541.62                                                                                                            | 864.96                                                                                                                                | 550.15                                                                                                                    | 878.59                                                                                                                                | 558.50                                                                                                            | 891.92                                                                                                                                |
| 2028     | 23.02                                                     | 1.60                                                           | 12.78                                                                                   | 516.37                                                                                                            | 824.64                                                                                                                                | 521.62                                                                                                                    | 833.02                                                                                                                                | 526.45                                                                                                            | 840.75                                                                                                                                |
| 2029     | 21.43                                                     | 1.60                                                           | 14.37                                                                                   | 491.36                                                                                                            | 784.71                                                                                                                                | 493.64                                                                                                                    | 788.35                                                                                                                                | 495.34                                                                                                            | 791.06                                                                                                                                |
| 2030     | 19.83                                                     | 1.60                                                           | 15.97                                                                                   | 466.61                                                                                                            | 745.18                                                                                                                                | 466.22                                                                                                                    | 744.55                                                                                                                                | 465.14                                                                                                            | 742.82                                                                                                                                |
| 2031     | 18.51                                                     | 1.32                                                           | 17.29                                                                                   | 442.10                                                                                                            | 584.46                                                                                                                                | 439.33                                                                                                                    | 580.79                                                                                                                                | 435.81                                                                                                            | 576.14                                                                                                                                |
| 2032     | 17.19                                                     | 1.32                                                           | 18.61                                                                                   | 417.84                                                                                                            | 552.38                                                                                                                                | 412.97                                                                                                                    | 545.94                                                                                                                                | 407.34                                                                                                            | 538.50                                                                                                                                |
| 2033     | 15.86                                                     | 1.32                                                           | 19.94                                                                                   | 393.81                                                                                                            | 520.62                                                                                                                                | 387.13                                                                                                                    | 511.78                                                                                                                                | 379.70                                                                                                            | 501.96                                                                                                                                |
| 2034     | 14.54                                                     | 1.32                                                           | 21.26                                                                                   | 370.02                                                                                                            | 489.17                                                                                                                                | 361.79                                                                                                                    | 478.28                                                                                                                                | 352.86                                                                                                            | 466.48                                                                                                                                |
| 2035     | 13.22                                                     | 1.32                                                           | 22.58                                                                                   | 346.47                                                                                                            | 458.03                                                                                                                                | 336.95                                                                                                                    | 445.44                                                                                                                                | 326.81                                                                                                            | 432.04                                                                                                                                |
| 2036     | 11.90                                                     | 1.32                                                           | 23.90                                                                                   | 323.15                                                                                                            | 427.21                                                                                                                                | 312.59                                                                                                                    | 413.25                                                                                                                                | 301.51                                                                                                            | 398.60                                                                                                                                |
| 2037     | 10.58                                                     | 1.32                                                           | 25.22                                                                                   | 300.06                                                                                                            | 396.68                                                                                                                                | 288.72                                                                                                                    | 381.69                                                                                                                                | 276.95                                                                                                            | 366.13                                                                                                                                |
| 2038     | 9.25                                                      | 1.32                                                           | 26.55                                                                                   | 277.20                                                                                                            | 366.46                                                                                                                                | 265.31                                                                                                                    | 350.74                                                                                                                                | 253.11                                                                                                            | 334.61                                                                                                                                |
| 2039     | 7.93                                                      | 1.32                                                           | 27.87                                                                                   | 254.57                                                                                                            | 336.54                                                                                                                                | 242.36                                                                                                                    | 320.40                                                                                                                                | 229.96                                                                                                            | 304.00                                                                                                                                |
| 2040     | 6.61                                                      | 1.32                                                           | 29.19                                                                                   | 232.16                                                                                                            | 306.92                                                                                                                                | 219.86                                                                                                                    | 290.66                                                                                                                                | 207.48                                                                                                            | 274.29                                                                                                                                |
| 2041     | 5.29                                                      | 1.32                                                           | 30.51                                                                                   | 209.97                                                                                                            | 277.59                                                                                                                                | 197.81                                                                                                                    | 261.50                                                                                                                                | 185.66                                                                                                            | 245.44                                                                                                                                |
| 2042     | 3.97                                                      | 1.32                                                           | 31.83                                                                                   | 188.08                                                                                                            | 248.64                                                                                                                                | 176.32                                                                                                                    | 233.10                                                                                                                                | 164.68                                                                                                            | 217.71                                                                                                                                |
| 2043     | 2.64                                                      | 1.32                                                           | 33.16                                                                                   | 166.42                                                                                                            | 220.01                                                                                                                                | 155.31                                                                                                                    | 205.32                                                                                                                                | 144.38                                                                                                            | 190.87                                                                                                                                |
| 2044     | 1.32                                                      | 1.32                                                           | 34.48                                                                                   | 144.89                                                                                                            | 191.54                                                                                                                                | 134.52                                                                                                                    | 177.84                                                                                                                                | 124.41                                                                                                            | 164.47                                                                                                                                |
| 2045     | 0.00                                                      | 1.32                                                           | 35.80                                                                                   | 123.57                                                                                                            | 163.36                                                                                                                                | 114.14                                                                                                                    | 150.90                                                                                                                                | 105.03                                                                                                            | 138.84                                                                                                                                |
| 2046     | 0.00                                                      | 0.00                                                           | 35.80                                                                                   | 102.46                                                                                                            | 0.00                                                                                                                                  | 94.17                                                                                                                     | 0.00                                                                                                                                  | 86.20                                                                                                             | 0.00                                                                                                                                  |
| 2047     | 0.00                                                      | 0.00                                                           | 35.80                                                                                   | 81.56                                                                                                             | 0.00                                                                                                                                  | 74.58                                                                                                                     | 0.00                                                                                                                                  | 67.93                                                                                                             | 0.00                                                                                                                                  |
| 2048     | 0.00                                                      | 0.00                                                           | 35.80                                                                                   | 60.86                                                                                                             | 0.00                                                                                                                                  | 55.38                                                                                                                     | 0.00                                                                                                                                  | 50.19                                                                                                             | 0.00                                                                                                                                  |
| 2049     | 0.00                                                      | 0.00                                                           | 35.80                                                                                   | 40.37                                                                                                             | 0.00                                                                                                                                  | 36.55                                                                                                                     | 0.00                                                                                                                                  | 32.96                                                                                                             | 0.00                                                                                                                                  |
| 2050     | 0.00                                                      | 0.00                                                           | 35.80                                                                                   | 20.09                                                                                                             | 0.00                                                                                                                                  | 18.09                                                                                                                     | 0.00                                                                                                                                  | 16.24                                                                                                             | 0.00                                                                                                                                  |
| $\Sigma$ |                                                           |                                                                | Z= 665.03                                                                               | $B_{1\%,B}^{rewetting}$ 14,818.6                                                                                  | $B_{2\%,B}^{rewetting}$ 14,872.9                                                                                                      | $B_{3\%,B}^{rewetting}$ = 14,932.1                                                                                        |                                                                                                                                       |                                                                                                                   |                                                                                                                                       |

Source: Own calculations.

Note: All values in € are in the present values of the year 2020. **Column 1** shows time horizon with  $t_0 = 2020, \dots, t, \dots, T = 2050$ . **Column 2** shows the remaining annual CO<sub>2</sub> emissions along the rewetting pathway. While **column 3** shows the quantity and point in time at which an annual CO<sub>2</sub> emission source is eliminated. **Column 4** shows the necessary elimination of annual CO<sub>2</sub>-emission sources summed up from 2020 to t along the rewetting pathway. It follows that the sum of all values in **column 4** from 2020 to 2050 gives Z and quantifies the overall CO<sub>2</sub> emission mitigation potential of the pathway by the time 2050. **Column 5** shows the politically justified budget to eliminate an annual source of one ton of CO<sub>2</sub> in time t based on the coal phase-out. Due to the set discount rate of 1 %, 2 % and 3 %,  $jb_{rt}^{annual source}$  varies in **column 5, 7 and 9**. **Columns 6, 8 and 10** show the politically justified budget per year regarding the corresponding quantity of eliminated annual CO<sub>2</sub> emission sources in that year. Cumulating the annual budget from 2020 to 2050 results in a total justified political budget  $B_{rm}^{rewetting}$ .

**Table A3.4. Pathway C: Calculations linked to Section 3.3**

| 1        | 2                                                         | 3                                                                 | 4                                                                                          | 5                                                                                                                | 6                                                                                                                                | 7                                                                                                                | 8                                                                                                                                | 9                                                                                                                | 10                                                                             |
|----------|-----------------------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Year     | Annual emissions from agricultural peatlands used (in Mt) | Elimination of an annual CO <sub>2</sub> -emission source (in Mt) | Elimination of an annual CO <sub>2</sub> -emission source summed up from 2020 to t (in Mt) | Justified Budget to eliminate an annual CO <sub>2</sub> -emission source in t = $jb_{rt}^{annual source}$ (in €) | Annual share of total Budget to eliminate an annual CO <sub>2</sub> -emission source in t = $jb_{rt}^{rewetting}$ (in Million €) | Justified Budget to eliminate an annual CO <sub>2</sub> -emission source in t = $jb_{rt}^{annual source}$ (in €) | Annual share of total Budget to eliminate an annual CO <sub>2</sub> -emission source in t = $jb_{rt}^{rewetting}$ (in Million €) | Justified Budget to eliminate an annual CO <sub>2</sub> -emission source in t = $jb_{rt}^{annual source}$ (in €) | Annual share of total Budget In million € $jb_{rt}^{rewetting}$ (in Million €) |
| t        | $X_{it}$                                                  | $\Delta X_{itm}^{rewetting}$                                      | $\sum_t^T X_{it}$                                                                          | r=1 %                                                                                                            | r=2 %                                                                                                                            | r=3 %                                                                                                            |                                                                                                                                  |                                                                                                                  |                                                                                |
| 2020     | 35.80                                                     | 0.00                                                              | 0.00                                                                                       | 725.59                                                                                                           | 0.00                                                                                                                             | 766.52                                                                                                           | 0.00                                                                                                                             | 811.41                                                                                                           | 0.00                                                                           |
| 2021     | 34.20                                                     | 1.60                                                              | 1.60                                                                                       | 698.52                                                                                                           | 1115.53                                                                                                                          | 733.75                                                                                                           | 1171.79                                                                                                                          | 771.99                                                                                                           | 1232.87                                                                        |
| 2022     | 32.61                                                     | 1.60                                                              | 3.19                                                                                       | 671.71                                                                                                           | 1072.72                                                                                                                          | 701.61                                                                                                           | 1120.48                                                                                                                          | 733.73                                                                                                           | 1171.77                                                                        |
| 2023     | 31.01                                                     | 1.60                                                              | 4.79                                                                                       | 645.17                                                                                                           | 1030.34                                                                                                                          | 670.11                                                                                                           | 1070.16                                                                                                                          | 696.58                                                                                                           | 1112.44                                                                        |
| 2024     | 29.41                                                     | 1.60                                                              | 6.39                                                                                       | 618.90                                                                                                           | 988.38                                                                                                                           | 639.22                                                                                                           | 1020.84                                                                                                                          | 660.52                                                                                                           | 1054.84                                                                        |
| 2025     | 27.82                                                     | 1.60                                                              | 7.99                                                                                       | 592.88                                                                                                           | 946.83                                                                                                                           | 608.94                                                                                                           | 972.48                                                                                                                           | 625.50                                                                                                           | 998.92                                                                         |
| 2026     | 26.22                                                     | 1.60                                                              | 9.58                                                                                       | 567.12                                                                                                           | 905.69                                                                                                                           | 579.26                                                                                                           | 925.07                                                                                                                           | 591.50                                                                                                           | 944.63                                                                         |
| 2027     | 24.62                                                     | 1.60                                                              | 11.18                                                                                      | 541.62                                                                                                           | 864.96                                                                                                                           | 550.15                                                                                                           | 878.59                                                                                                                           | 558.50                                                                                                           | 891.92                                                                         |
| 2028     | 23.02                                                     | 1.60                                                              | 12.78                                                                                      | 516.37                                                                                                           | 824.64                                                                                                                           | 521.62                                                                                                           | 833.02                                                                                                                           | 526.45                                                                                                           | 840.75                                                                         |
| 2029     | 21.43                                                     | 1.60                                                              | 14.37                                                                                      | 491.36                                                                                                           | 784.71                                                                                                                           | 493.64                                                                                                           | 788.35                                                                                                                           | 495.34                                                                                                           | 791.06                                                                         |
| 2030     | 19.83                                                     | 1.60                                                              | 15.97                                                                                      | 466.61                                                                                                           | 745.18                                                                                                                           | 466.22                                                                                                           | 744.55                                                                                                                           | 465.14                                                                                                           | 742.82                                                                         |
| 2031     | 17.85                                                     | 1.98                                                              | 17.95                                                                                      | 442.10                                                                                                           | 876.69                                                                                                                           | 439.33                                                                                                           | 871.19                                                                                                                           | 435.81                                                                                                           | 864.21                                                                         |
| 2032     | 15.86                                                     | 1.98                                                              | 19.94                                                                                      | 417.84                                                                                                           | 828.57                                                                                                                           | 412.97                                                                                                           | 818.92                                                                                                                           | 407.34                                                                                                           | 807.76                                                                         |
| 2033     | 13.88                                                     | 1.98                                                              | 21.92                                                                                      | 393.81                                                                                                           | 780.93                                                                                                                           | 387.13                                                                                                           | 767.67                                                                                                                           | 379.70                                                                                                           | 752.94                                                                         |
| 2034     | 11.90                                                     | 1.98                                                              | 23.90                                                                                      | 370.02                                                                                                           | 733.76                                                                                                                           | 361.79                                                                                                           | 717.43                                                                                                                           | 352.86                                                                                                           | 699.72                                                                         |
| 2035     | 9.91                                                      | 1.98                                                              | 25.89                                                                                      | 346.47                                                                                                           | 687.05                                                                                                                           | 336.95                                                                                                           | 668.17                                                                                                                           | 326.81                                                                                                           | 648.06                                                                         |
| 2036     | 7.93                                                      | 1.98                                                              | 27.87                                                                                      | 323.15                                                                                                           | 640.81                                                                                                                           | 312.59                                                                                                           | 619.87                                                                                                                           | 301.51                                                                                                           | 597.89                                                                         |
| 2037     | 5.95                                                      | 1.98                                                              | 29.85                                                                                      | 300.06                                                                                                           | 595.03                                                                                                                           | 288.72                                                                                                           | 572.53                                                                                                                           | 276.95                                                                                                           | 549.19                                                                         |
| 2038     | 3.97                                                      | 1.98                                                              | 31.83                                                                                      | 277.20                                                                                                           | 549.69                                                                                                                           | 265.31                                                                                                           | 526.11                                                                                                                           | 253.11                                                                                                           | 501.91                                                                         |
| 2039     | 1.98                                                      | 1.98                                                              | 33.82                                                                                      | 254.57                                                                                                           | 504.81                                                                                                                           | 242.36                                                                                                           | 480.60                                                                                                                           | 229.96                                                                                                           | 456.00                                                                         |
| 2040     | 0.00                                                      | 1.98                                                              | 35.80                                                                                      | 232.16                                                                                                           | 460.38                                                                                                                           | 219.86                                                                                                           | 435.99                                                                                                                           | 207.48                                                                                                           | 411.43                                                                         |
| 2041     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 209.97                                                                                                           | 0.00                                                                                                                             | 197.81                                                                                                           | 0.00                                                                                                                             | 185.66                                                                                                           | 0.00                                                                           |
| 2042     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 188.08                                                                                                           | 0.00                                                                                                                             | 176.32                                                                                                           | 0.00                                                                                                                             | 164.68                                                                                                           | 0.00                                                                           |
| 2043     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 166.42                                                                                                           | 0.00                                                                                                                             | 155.31                                                                                                           | 0.00                                                                                                                             | 144.38                                                                                                           | 0.00                                                                           |
| 2044     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 144.89                                                                                                           | 0.00                                                                                                                             | 134.52                                                                                                           | 0.00                                                                                                                             | 124.41                                                                                                           | 0.00                                                                           |
| 2045     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 123.57                                                                                                           | 0.00                                                                                                                             | 114.14                                                                                                           | 0.00                                                                                                                             | 105.03                                                                                                           | 0.00                                                                           |
| 2046     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 102.46                                                                                                           | 0.00                                                                                                                             | 94.17                                                                                                            | 0.00                                                                                                                             | 86.20                                                                                                            | 0.00                                                                           |
| 2047     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 81.56                                                                                                            | 0.00                                                                                                                             | 74.58                                                                                                            | 0.00                                                                                                                             | 67.93                                                                                                            | 0.00                                                                           |
| 2048     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 60.86                                                                                                            | 0.00                                                                                                                             | 55.38                                                                                                            | 0.00                                                                                                                             | 50.19                                                                                                            | 0.00                                                                           |
| 2049     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 40.37                                                                                                            | 0.00                                                                                                                             | 36.55                                                                                                            | 0.00                                                                                                                             | 32.96                                                                                                            | 0.00                                                                           |
| 2050     | 0.00                                                      | 0.00                                                              | 35.80                                                                                      | 20.09                                                                                                            | 0.00                                                                                                                             | 18.09                                                                                                            | 0.00                                                                                                                             | 16.24                                                                                                            | 0.00                                                                           |
| $\Sigma$ |                                                           |                                                                   | Z=<br>714.6                                                                                |                                                                                                                  | $B_{1\%,C}^{rewetting}$<br>15,936.7                                                                                              |                                                                                                                  | $B_{2\%,C}^{rewetting}$<br>16,003.8                                                                                              |                                                                                                                  | $B_{3\%,C}^{rewetting} =$<br>16,071.2                                          |

Source: Own calculations.

Note: **Column 1** shows time horizon with  $t_0 = 2020, \dots, t, \dots, T = 2050$ . **Column 2** shows the remaining annual CO<sub>2</sub> emissions along the rewetting pathway. While **column 3** shows the quantity and point in time at which an annual CO<sub>2</sub> emission source is eliminated. **Column 4** shows the necessary elimination of annual CO<sub>2</sub>-emission sources summed up from 2020 to t along the rewetting pathway. It follows that the sum of all values in **column 4** from 2020 to 2050 gives Z and quantifies the overall CO<sub>2</sub> emission mitigation potential of the pathway by the time 2050. **Column 5** shows the politically justified budget to eliminate an annual source of one ton of CO<sub>2</sub> in time t based on the coal phase-out. Due to the set discount rate of 1 %, 2 % and 3 %,  $jb_{rt}^{annual source}$  varies in **column 5, 7 and 9**. **Columns 6, 8 and 10** show the politically justified budget per year regarding the corresponding quantity of eliminated annual CO<sub>2</sub> emission sources in that year. Cumulating the annual budget from 2020 to 2050 results in a total justified political budget  $B_{rm}^{rewetting}$ .

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## CHAPTER 4

# HOW WELL ARE PEATLANDS UNDERSTOOD? LESSONS FROM MEASURING SUBJECTIVE AND OBJECTIVE KNOWLEDGE

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Submitted



## Abstract

Peatland rewetting is an efficient instrument to curb emissions and mitigate climate change. Even though knowledge is crucial in shaping environmental concern and support for climate policies, little is known about public knowledge of peatlands. Using a nationwide survey, this paper analyses self-reported (subjective) knowledge and measured (objective) knowledge in Germany – one of the world’s largest emitters of greenhouse gas emissions from drained peatlands and the EU member with the highest proportion of drained peatlands. We find that individuals with low measured knowledge tend to overestimate their abilities, while those with high measured knowledge exhibit a strong underestimation (which reflects a Dunning-Kruger effect). Analysing the drivers of over- and underestimation, we show that individuals who overestimate their knowledge are associated with being less open to new information. We also find a gap between subjective and objective knowledge, and examine the extent to which the disparity correlates with socioeconomic, psychological, and attitudinal determinants

**Keywords:** Peatland rewetting, Knowledge, Dunning-Kruger effect, Objective-subjective-gap, Climate change, Overconfidence, Underconfidence, AOT

## 1. Introduction

Degraded peatlands have a disproportionate climate impact, contributing 3-5 % of global anthropogenic CO<sub>2</sub> emissions while occupying only 0.3 % of the world's land surface (Joosten, 2016; Joosten et al., 2016). Germany records the EU’s highest share of drained peatlands per country and the highest total emissions from drained peatlands, especially due to agricultural use, making it a significant contributor to global peatland-related emissions (UNEP, 2022). More than 90 % of Germany's peatland area has been drained, largely for agriculture, which accounts for 7 % of the national anthropogenic GHG emissions (UBA, 2022; Tiemeyer et al., 2020). Agricultural use is the leading cause of peatland drainage in Germany and numerous other EU member states (UNEP, 2022). Rewetting these areas is an effective strategy for reducing emissions and mitigating climate change (Günther et al., 2020; Humpenöder et al., 2020; Leifeld and Menichetti, 2018), but it requires a transition, particularly in the agricultural sector, as farming practices must adapt to wet conditions (Tanneberger et al., 2021a). This transformation is both complex and profound. It spans multiple sectors and demands significant public funding, alongside political leadership, given the time constraints driven by high emissions and climate change (Sommer and Frank, 2024; Sommer et al., 2024; Meyer-Jürshof et al., 2025).

In democratic nations, public acceptance of peatland rewetting is crucial for designing and implementing the transformation process (cf. Khatibi et al., 2021). Lack of public support can impede policy adoption, undermine compliance, and diminish the overall effectiveness of climate actions (Lipari et al., 2024; Bergquist et al., 2022). Research has shown that knowledge among the population is crucial in shaping environmental concern and support for climate policies (cf., Khatibi et al., 2021; e.g., Shi et al., 2016).

Despite the intensifying global political debate about peatland rewetting as a measure to reduce emissions (UNEP, 2022b), little is known about the nationwide public's level of knowledge on this issue. Addressing this gap is essential for developing targeted communication strategies (cf., Light et al., 2022). Furthermore, enhancing public knowledge not only fosters support for the rewetting process but also empowers citizens to form well-founded opinions and make informed decisions (cf., Shi, 2016).

Previous research on public knowledge, perceptions and preferences concerning peatlands has predominantly focused on specific stakeholder groups and experts, for instance, peatland visitors and recreationists in England (Flint and Jennings, 2022; Martino et al., 2022), peatland farmers in Germany or the Netherlands (Hünnebeck-Wells et al., 2024; Norris et al., 2021; Schaller et al., 2011) or members from the water board, farm advisory, administration, conservationists or scientists as involved by Buschmann et al. (2020) for six case studies in different European peatland regions. Recent research highlights the role of knowledge and relational values within local individuals and peatland-adjacent communities in Ireland (Flood et al., 2022, 2021), Germany (Heindorf et al., 2024), and Estonia (Päll and Pungas-Kohv, 2024). Nationwide surveys on peatlands remain scarce. To date, research involving the general public have so far been largely limited to peatland-rich regions like Scotland (Facciola et al., 2020; Byg et al., 2017) or the Finnish Ostrobothnia region (Tolvanen et al., 2012). An Estonian study revealed that peatlands are important to most people across the country, with 38.7% of the respondents visiting peatlands several times a year and only 8.6 % stating that they did not visit peatlands (Pungas-Kohv et al., 2015). Kuhn et al. (2024) investigated the public perception of ecosystem restoration for carbon dioxide removal by comparing peatlands, forests and seagrass meadows in Germany. However, to our knowledge, no nationwide survey has yet systematically assessed the general population's knowledge about peatlands - the understanding of how knowledge is distributed across different socioeconomic and demographic groups is limited. This is surprising given the urgency of actions to mitigate climate change and the potential of peatland rewetting as a cost-effective strategy (Niemi et al., 2024; Leifeld and

Menichetti, 2018). Our study provides deeper insights into the measurement of peatland knowledge with the help of a nationwide survey on knowledge about peatlands and rewetting. Germany serves as an ideal case study due to its extensive share of drained peatlands and EU-wide significance as a large emitter of emissions from drained peatlands (UNEP, 2022). The German government has adopted a national peatland protection strategy (BMUV, 2022), which stipulates a reduction of annual emissions from drained peatlands by 5 Mt of CO<sub>2</sub>e by 2030, equivalent to approximately 10 % of current peatland emissions. However, following a rewetting pathway in line with the climate targets (e.g., Tanneberger et al., 2021b), Germany needs to set more ambitious reduction targets and will face a deep transition and require policy measures primarily affecting the agricultural sector (Sommer and Frank, 2024; Chen et al., 2024; Wichmann and Nordt, 2024; Grethe et al., 2021).

By comparing self-reported knowledge (henceforth subjective knowledge) with factual knowledge (henceforth objective knowledge), we explore the association between objective knowledge levels and self-assessment accuracy. We conducted an Internet-based survey with a quota-representative sample of the general population of Germany. Here, we developed 10 questions in a quiz-style to systematically measure objective knowledge about peatlands and peatland rewetting for the first time. Furthermore, we analyse associations between knowledge types and socioeconomic, psychological, and attitudinal determinants. For example, we measure people's willingness to reflect and revise their own opinions when new information (including contradictory to current beliefs) is available (actively open-minded thinking, henceforth AOT; Haran et al., 2013).

Our findings reveal a close link between measured knowledge levels and self-assessment accuracy, confirming an overconfidence in knowledge about peatlands and peatland rewetting with low objective knowledge and an underconfidence with high objective knowledge. We provide evidence for the Dunning-Kruger effect (Kruger and Dunning, 1999) and consider over- and underconfidence (self-assessment accuracy) in the context of peatlands. Our findings have wide implications for the development of communication strategies in the field of peatland rewetting. While existing literature predominantly focuses on overconfidence (e.g., Light et al., 2022; Ortoleva and Snowberg, 2015; Sundbland et al., 2009), underconfidence should also be considered in the context of science communication. Hence, we correlate over- and underconfidence with the determinants, which enables us to identify drivers for both.

By systematically addressing subjective and objective knowledge as well as over- and underconfidence, this study provides the foundation for designing more effective

communication strategies and policy interventions for improving public understanding of peatland rewetting.

## **2. Methods**

### **2.1. Study design**

In August 2024, we conducted a nationwide, Internet-based survey with representatives of the general population in Germany (N = 608), administered by a professional survey company. The study combined quiz-based assessments of objective knowledge with self-reported measures to capture subjective knowledge and other relevant dimensions.

The survey assessed the following key dimensions:

1. Socioeconomic determinants: age, sex assigned at birth, education, income, and geographical aspects, such as residency in peatland-rich areas.
2. Psychological determinants:
  - Actively open-minded thinking (AOT): capturing participants' willingness to revise beliefs based on evidence.
  - Time preference: measuring inclination toward immediate vs. long-term benefits.
  - Risk preference: assessing tolerance for uncertainties, such as economic risks associated with policies.
3. Attitudinal determinants: Environmental values, trust in science, connection to rural areas, family history of contributing to drainage, and political view.

Ethical approval for the study was obtained prior to data collection (Appendix A3.1 in Chapter 5).

### **2.2. Variables and measurement**

In 6 out of 10 questions, four answer options were given, with only one being correct. In one question, two options are correct. Participants could select all, some, or none of the options. One point was awarded for each question that was answered fully correctly. For 3 questions, participants were asked to select the only correct answer. All variables and measurements can be found in Table A.1 of the Appendix.

### **2.3. Measured knowledge**

Objective knowledge was assessed using a 10-question quiz (Appendix A1), divided into three thematic categories:

- General knowledge about peatlands – covering the foundational understanding of peatland ecosystems.
- Utilisation, distribution, emissions, and governance – addressing the use of peatlands, their spatial distribution, associated emissions, and relevant political processes.
- Wet use and paludiculture – exploring sustainable practices, including wetland use and paludiculture.

Seven questions offered four answer options, allowing participants to select all, none, or any combination of the options. For the analysis, the total score ranged from 0 to 10 points. Responses were coded as correct (1 point) only if all correct answers were selected and no incorrect options were chosen. This scoring method minimised the likelihood of guessing and ensured that scores reflected genuine knowledge. For the remaining three questions, only one correct answer was possible.

#### **2.4. Subjective knowledge and self-assessment accuracy**

Subjective knowledge was measured by asking participants to rate their (objective) knowledge about peatlands on a scale from 0 (no knowledge) to 10 (excellent knowledge) before taking the quiz. Self-assessment accuracy provides a quantitative measure of how well participants' subjective knowledge aligns with their objective knowledge. Self-assessment accuracy was calculated as the difference between subjective knowledge and objective knowledge scores obtained from the quiz:

$$\text{Self – Assessment Accuracy} = \text{Subjective Knowledge} - \text{Objective Knowledge}$$

- A positive value indicates overestimation of knowledge.
- A negative value indicates underestimation of knowledge.
- A value of 0 reflects an accurate self-assessment.

#### **2.5. Correlation analysis**

We apply an exploratory approach (cf. Schwab and Held, 2020), which provides an overview of the determinants influencing knowledge as well as over- and underconfidence and serves to identify patterns within the data.

The association between the determinants and subjective and objective knowledge was assessed using Spearman's rank correlation, as it is suitable for ordinal data and does not assume a linear relationship. For binary variables, the point-biserial correlation coefficient was used to examine their association with objective and subjective knowledge.

Due to a more intuitive interpretation of Fig. 2, we transformed the scale of self-assessment accuracy of from -10 to 10 to a scale where high negative values are high values within the group of underestimating participants.

### **2.6. R-Packages**

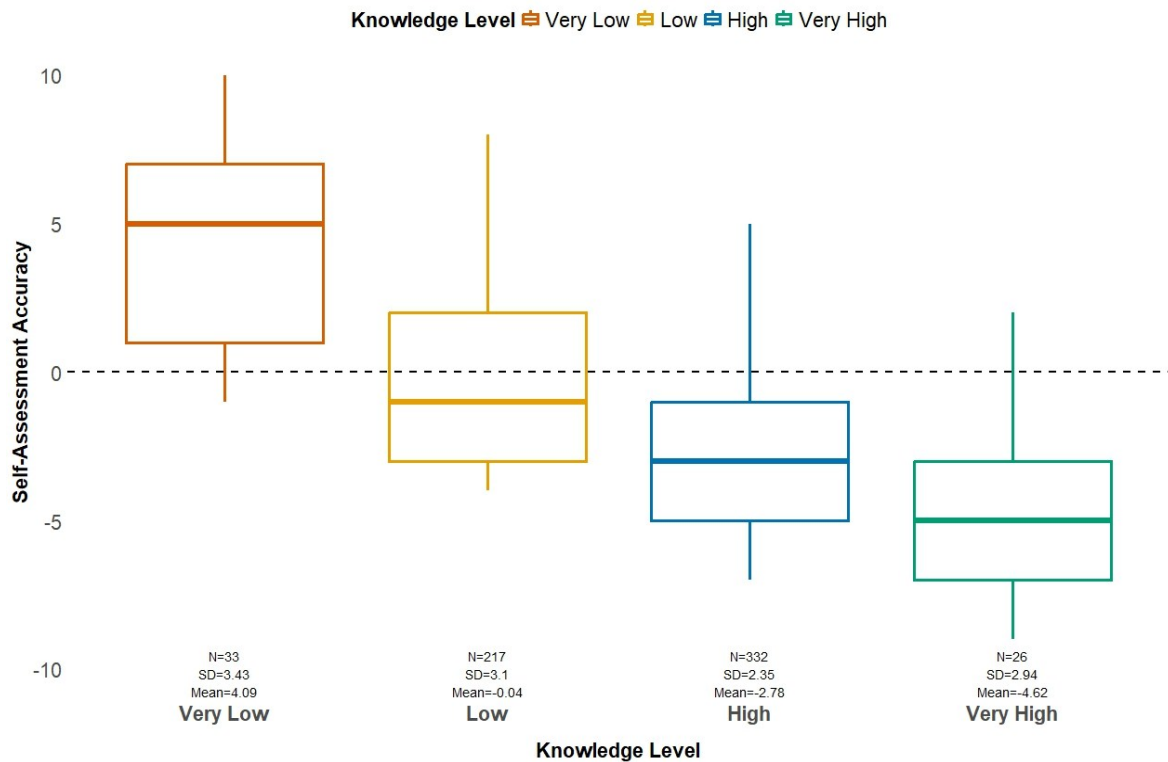
The analysis was conducted using R version 4.4.1, with the following packages: readxl, plyr, dplyr, and ggplot2.

## **3. Results**

### **3.1. The Dunning-Kruger effect applies to peatland knowledge**

Individuals with a very low level of measured knowledge tend to overestimate their abilities, while those with high and very high measured knowledge exhibit a strong underestimation. The self-assessment accuracy of knowledge is closely linked to the measured knowledge level (Fig. 1). The group with very low knowledge shows a mean self-assessment accuracy of 4.09, indicating a considerable overestimation of their own knowledge level. Within the group of a low knowledge level, the self-assessment accuracy is, with a mean of -0.04, the highest among all knowledge levels. In contrast, individuals with a high and very high knowledge level show an underestimation of their knowledge. The group with a high knowledge level has a mean of -2.78. The underestimation with an average self-assessment accuracy of -4.62 for the very high knowledge level is the highest among all levels. The distribution of participants indicates that the majority (358 out of 608, approximately 58.9 %) possess a high level of knowledge while tending toward underestimation, while 217 out of 608 (approximately 35.7 %) assess themselves fairly accurately, and 33 out of 608 (approximately 5.4 %) exhibit a strong overestimation of their abilities. The average self-assessment accuracy is -1.51, while 67.3 % are underestimating themselves, 24.8 % are overestimating, and 8.4 % are accurate about their self-assessment (Appendix A2).

**Figure 1: Self-assessment accuracy by aggregated knowledge levels**

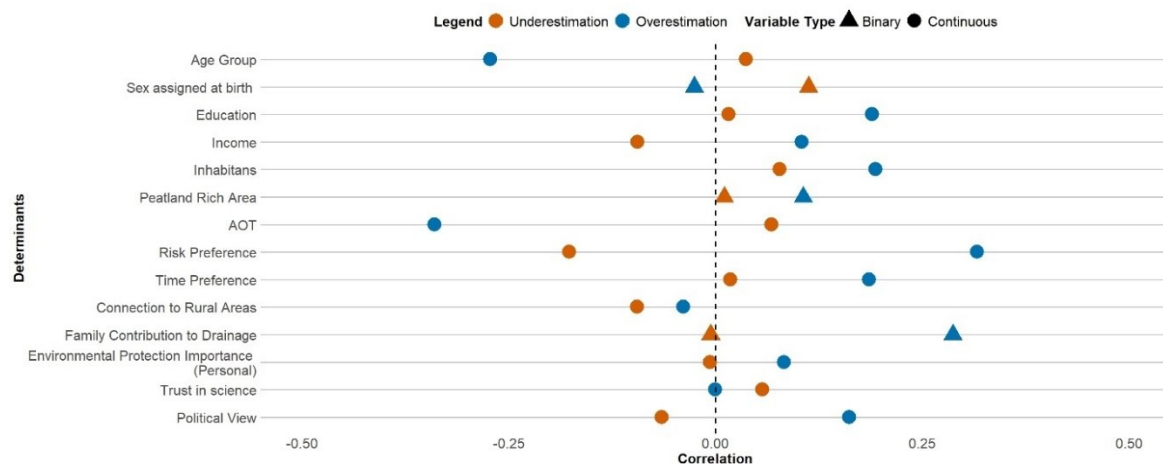


**Source:** Own presentation, N = 608.

**Notes:** The figure illustrates self-assessment accuracy (before the quiz) as a function of aggregated measured knowledge levels. The categorization was carried out in such a way that the 11 categories (based on the 10 knowledge questions) are roughly equally distributed across the four knowledge groups: Very Low Knowledge category 0 to 1, Low knowledge category 2 to 4, High knowledge category 5 to 7, and Very High knowledge category 8 to 10.

The boxplots represent the distribution of self-assessment accuracy within each knowledge group. On the y-axis, self-assessment accuracy is plotted, reflecting the difference between self-assessed and measured knowledge. Positive values indicate overestimation, while negative values indicate underestimation of the knowledge. The x-axis categorises participants into the four knowledge groups.

The determinants influencing measured and self-reported knowledge differ in both the direction and strength of their association (Fig. 2). Correlating self-assessment accuracy (as defined as over- and underconfidence) with the determinants gives insights into the associations within the three categories: socioeconomic, psychological, and attitude.

**Figure 2: Correlation between self-assessment accuracy and determinants**

**Source:** Own presentation, N = 608.

**Notes:** Spearman's rank correlation coefficients are presented for ordinal determinants, while Point-Biserial-Correlation coefficients are shown for binary determinants (sex assigned at birth, peatland rich area and family contribution to drainage). Age group: 5 categories (18-30, 31-40, 41-50, 51-60, 60+); sex assigned at birth: 0 = Male, 1 = Female; peatland rich areas: 0 = Not peatland rich, 1 = peatland rich; political view: 0 = Very Left, 10 = Very Right; family contribution to drainage: 0 = Disagree, 1 = Agree; inhabitants: describes the population size of the primary place of residence. For further description of the variables, please refer to Section 2.2.

The y-axis shows the determinants, and the x-axis represents the correlation values, ranging between -0.5 and +0.5. The points and triangles represent the strength and direction of the correlations.

Green icons are the correlation with the overestimation, and red icons are the correlation with underestimation. Points represent continuous variables, while a triangle is a binary one. Self-assessment accuracy is a measurement from -9 to 10. Negative values indicate an underestimation, while positive numbers indicate an overestimation of the knowledge. People underestimating their knowledge n = 401, people overestimating their knowledge n = 150 and people who have valued their own knowledge right n = 61. We transformed the negative values from the underestimation to positive values for simplification of interpretation. So now higher values of underestimation are equal to a higher underestimation, and high values of overestimation are equal to a higher overestimation. Correlation values are in Table A3.1 in Appendix A3.

Figure 2 shows the extent to which people's over- and underestimation is correlated with the determinants. Of particular importance are the determinants that exhibit a large distance and act in different directions between the over- and underestimation of knowledge. Within the group of overconfident people (i.e. an overestimation of subjective knowledge), a higher overestimation is associated with a lower age, a lower openness to new information. The biggest distance to underestimation and the strongest positive correlation with overestimation exhibits risk preference. Also, a higher income and if the family contributed to drainage and a tendency to right-wing political views are positively correlated with higher overestimation.

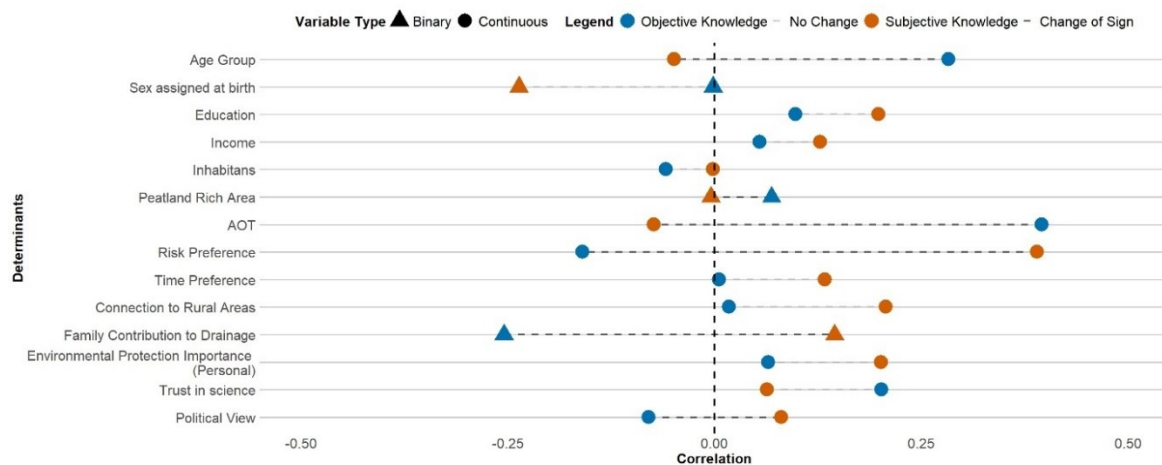
On the other hand, within the group of people who are underconfident (i.e., an underestimation of subjective knowledge), a greater underestimation is positively associated with a higher openness to new information, a lower risk preference, and a higher trust in science. A negative

association exists between the determinants of income and risk preference. Furthermore, within the underconfidence cohort, a greater degree of underestimation tends to be linked to the female sex and having a more left-wing political view. The determinants educational level, peatland rich area, whether the family contributed to drainage, and (personal) environment protection importance are associated with overconfidence but have almost no correlation with underconfidence. For the determinants trust in science and being assigned to the female sex, there is a positive correlation within the group of underconfidence but nearly none within the overconfidence group.

**3.2. Subjective and objective knowledge accuracy shows a gap along the determinants**

Figure 3 illustrates the correlations between measured knowledge and self-reported knowledge in the three categories of determinants: socioeconomic, psychological, and attitude (for details, see Section 2.2). The discrepancies in how these determinants relate to the two knowledge types about peatlands and peatland rewetting are pointed out.

**Figure 3: Correlation between knowledge and determinants**



Source: Own presentation. N = 608.

**Notes:** Spearman’s rank correlation coefficients are presented for ordinal determinants, while Point-Biserial-Correlation coefficients are shown for binary determinants (sex assigned at birth, peatland rich area and family contribution to drainage). Age group: 5 Categories (18-30, 31-40, 41-50, 51-60, 60+); Sex assigned at birth: 0 = Male, 1 = Female; Peatland rich areas: 0 = Not peatland rich, 1 = Peatland rich; Political view: 0 = Very Left, 10 = Very right; Family contribution to drainage: 0 = Disagree, 1 = Agree; Inhabitans: Describes the population size of the primary place of residence. For further description of the variables, please refer to Section 2.2. Correlation values are in Table A3.2 in Appendix A3.

The y-axis shows the determinants, and the x-axis represents the correlation values, ranging between -0.5 and +0.5. The points and triangles represent the strength and direction of the correlations. Blue icons are the correlation with the measured knowledge, and red icons are the correlation with subjective knowledge. Points represent continuous variables, while a triangle is a binary one. The line between the icons represents the distance between both correlations for each variable. If there is a sign change between subjective

## CHAPTER 4

and objective knowledge within one variable, the lines are bolded in black. And vice versa, if there is no sign change, then the colouring is transparent.

The determinants of education, income, time preference, connection to rural areas, and (personal) environmental protection importance are positively correlated with self-reported knowledge rather than with measured knowledge. In contrast, for trust in science, the relationship is reversed, with measured knowledge showing a stronger positive correlation than self-reported knowledge.

Sex assigned at birth shows a negative correlation with self-reported knowledge, and almost no correlation with measured knowledge. This suggests that individuals assigned to the female sex are more negatively correlated with subjective knowledge compared to individuals assigned to the male sex. The determinant inhabitants demonstrate a near-zero correlation with self-reported knowledge but a negative correlation with measured knowledge. This indicates that individuals living in areas with higher population densities tend to have lower levels of measured knowledge, while their self-reported knowledge remains unaffected.

Variables exhibiting a wide difference in correlation with a sign change provide interesting insights: Both, age group and AOT are negatively correlated with self-reported knowledge but positively correlated with measured knowledge. Participants who were open to considering new information and willing to rethink their views critically are positively associated with higher objective knowledge.

Risk preference demonstrates a considerable difference in correlation, including a change in sign. While measured knowledge is negatively correlated with risk preference, it is the determinant most strongly and positively correlated with self-reported knowledge. Similarly, family contributed to drainage and political view are negatively correlated with measured knowledge but positively correlated with self-reported knowledge. Specifically, individuals who reported that their family contributed to drainage show a positive correlation with self-reported knowledge and a negative correlation with measured knowledge compared to those who did not report such contributions. Likewise, individuals with a right-leaning political view exhibit a positive correlation with self-reported knowledge but a negative correlation with measured knowledge.

In contrast, peatland rich areas shows almost no correlation with self-reported knowledge but a positive correlation with measured knowledge. This suggests that individuals living in peatland-rich areas have higher levels of measured knowledge compared to those in areas without significant peatland, while their self-reported knowledge remains unaffected.

#### 4. Discussion and implications

Our results show a considerable gap between objective and subjective knowledge. This aligns with the findings of Stoutenborough and Vedlitz (2014), who find a difference in objective and subjective knowledge in the context of climate change. Relatedly, Li and Zhao (2019) find distinct effects of objective and subjective knowledge on the acceptance of transportation policies. The adequate measurement of knowledge is important to capture the effect of knowledge on policy support and provides a basis for a well-founded scientific debate (cf., Bergquist et al., 2022; Light et al., 2022; Drews and van den Bergh, 2016; Shi et al., 2016; Stoutenborough and Vedlitz, 2014).

Furthermore, some studies show that measured knowledge is positively associated with policy support, while there is no such link between subjective knowledge and policy support observed (cf., Drews and van den Bergh, 2016). But there are also studies stating that other factors beyond knowledge can affect climate change concern, policy support, acceptance, and behavioural change (cf., Lipari et al., 2024; Stoutenborough and Vedlitz, 2014). A systematic quantitative review from Khatibi (2021) shows a strong positive link between public knowledge and engagement.

The literature shows that a differentiation between objective and subjective knowledge is crucial. We can show differences among determinants and their associations with objective and subjective knowledge. This underlines the need to differentiate between both knowledge types and further provides insight into the drivers of each.

Subjective knowledge assessments distort perceptions of societal challenges or unintentionally reflect people's lack of knowledge, as seen with determinants like age and AOT. While subjective knowledge may suggest targeting older individuals or those with high AOT for knowledge communication, objective knowledge reveals that these targeted individuals often possess factual knowledge. Our findings suggest that communication efforts should focus on groups with objectively lower knowledge, such as younger individuals or those with low AOT, to ensure effective interventions.

Relying solely on subjective assessments runs the risk of misrepresenting the lack of knowledge and may lead to ill-directed communication strategies. The occurrence of sign changes reveals critical gaps between objective and subjective knowledge. It is important to highlight these discrepancies to create awareness and consider this for any type of policy design and development. When objective knowledge, e.g. about peatland rewetting, is incorrect or insufficient, informed decision-making is difficult (cf., Light et al., 2022; Fernbach et al., 2019). Bergquist et al. (2022) describe in a meta-analysis on determinants of public opinion about

climate change taxes and laws that knowledge is a necessary but not sufficient precondition. This highlights the importance of knowledge while also underscoring the complexity of factors influencing policy measures' support (Bergquist et al., 2022; Drews and van den Bergh, 2016). Shi et al. (2016) go one step further and summarise that the suggestion that knowledge has only a limited effect on shaping concern about climate change is an attribution to measurement error in knowledge. They further show that an objective measurement appears to be more qualified than a subjective one to explain climate change concerns. Discrepancies between both methods highlight the importance of carefully designed measurements to capture nuanced constructs. By addressing these methodological questions (Bergquist, 2022; Fischer et al., 2019; Shi, 2015), this study contributes to improving the accuracy and efficiency of knowledge assessments, with implications for peatland-related research.

Our results confirm a pattern consistent with the Dunning-Kruger effect (Kruger and Dunning, 1999): individuals with low objective knowledge tend to overestimate their abilities, while those with high objective knowledge often underestimate theirs. It is important to address this mismatch, as overconfidence is a factor for ideological extremeness, voter turnout, partisan identification (Ortoleva and Snowberg, 2015), and the spreading of low-quality information via social media (Lyons et al., 2021). Also, the findings of Light et al. (2022), Motta et al. (2018) and Fernbach et al. (2019) show that the most extreme opponents of scientific consensus tend to be those who are the most overconfident in their knowledge. Also, an association between the acceptance of pseudoscientific beliefs and supporting non-experts' role in policy-making and the Dunning-Kruger effect is identified by previous studies (Arroyo-Barrigüete et al., 2023; Motta et al., 2018). Consequently, it can be derived from the literature that overconfidence can be a risk for the support of peatland rewetting policies, making it essential to consider communication strategies.

By correlating with determinants, we provide initial insights into the drivers of overconfidence. The results show that participants with higher overconfidence in their knowledge tend to be less open to new information. Our findings can also be linked to Haran et al. (2013), who show that higher AOT was linked to greater persistence in information search, improved estimate accuracy, and reduced overconfidence. Overall, for information that predicts future outcomes, actively open-minded thinkers are more likely to make accurate forecasts. Also, our data show individuals with high overconfidence are associated with higher education and a connection to rural areas and that the environment is important to them. This indicates that those people think they do know a lot about peatlands due to their education or their attitude (connection to rural areas, the environment is important). This is an important recognition for identifying target

individuals for science communication, selecting suitable communication measures and policy design.

However, our data also reveal that the majority of people have a high to very high level of objective knowledge of peatlands and tend to be underconfident in this knowledge. Based on this high level of knowledge, we suggest that knowledge communication in Germany about peatlands can also include a high and probably complex level, trusting the audience's ability to engage. This approach could trigger three potential effects: (1) it can further improve the level of knowledge of relatively well-informed people (which, according to our data, makes up the majority), (2) it can address underconfidence, which not only influences individual decision-making (Ahmad, 2020) but may also prevent underconfident individuals from sharing their objective knowledge within their environment and public discourse and (3) it can help overconfident individuals recognize the complexity of the issue, offering an opportunity for self-reflection.

By systematically addressing subjective and objective knowledge as well as over- and underconfidence, this study provides the foundation for designing more effective communication strategies and policy interventions for improving public understanding of peatland rewetting.

Peatland (rewetting) research is a relatively young field, but its potential to contribute to emission and climate change mitigation is significant. There is no systematic measurement of public knowledge regarding drainage-based peatland use and peatland rewetting in those countries facing the need for peatland rewetting, underscoring the demand for future research. Valuable insights can be gained from exploring these countries, due to differing environmental concerns, climate policies, and narratives about peatland drainage, use and as a resource.

It seems promising to systematically address other populations' knowledge of peatlands (e.g., farmers, people from peatland-rich areas), including socioeconomic, psychological, and attitude determinants. Moreover, panel data (instead of utilising cross-sectional data) could be used to study developments over time. Additionally, examining the role of emotions as a potential mechanism in shaping overconfidence and decision-making processes may provide important findings for a better understanding of peatlands.

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## 6. Appendices

### A1: Variables and Measurements

**Table A1.1: Description of the variables and measurement**

| Label                             | Question/Statement                                                                                                                    | Range of Scale | Values (incl. comments)                                                                                                                                                                                                                           |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Objective Knowledge               | 10 Questions out of a quiz                                                                                                            | 0-10           | Participants' objective knowledge was categorised into 11 levels based on their achieved score, ranging from 0 (lowest) to 10 (highest).                                                                                                          |
| Self-Reported Knowledge           | "How well do you personally think you know about peatlands?"                                                                          | 1-11           | 1 = Very Poor, 11 = Very Good.                                                                                                                                                                                                                    |
| Age Group                         | "How old are you?"                                                                                                                    | 1-5            | The age was further categorized into five groups: 1 = 18-30, 2 = 31-40, 3 = 41-50, 4 = 51-60, 5 = 60+.                                                                                                                                            |
| Sex assigned at birth             | "What is your sex (according to the birth register)?"                                                                                 | 0-1            | Male = 0<br>Female = 1                                                                                                                                                                                                                            |
| Highest Educational Qualification | "What is your highest educational qualification?"                                                                                     | 1-7            | 1 = No qualification, 2 = Basic secondary school (Hauptschulabschluss), 3 = Intermediate secondary school (Realschulabschluss), 4 = University entrance qualification (Abitur), 5 = Bachelor's degree, 6 = Master's degree/Diploma, 7 = Doctorate |
| Inhabitants                       | "Approximately, how many inhabitants does your primary place of residence have?"                                                      | 1-7            | 1 = <2,000, 2 = 2,000-5,000, 3 = 5,000-20,000, 4 = 20,000-50,000, 5 = 50,000-100,000, 6 = 100,000-500,000, 7 = 500,000+.                                                                                                                          |
| Income                            | "When considering all income sources together, what is the current monthly net household income of all household members?"            | 1-10           | 1 = <€1,000, 2 = €1,000-1,499, 3 = €1,500-1,999, 4 = €2,000-2,499, 5 = €2,500-2,999, 6 = €3,000-3,499, 7 = €3,500-3,999, 8 = €4,000-4,499, 9 = €4,500-4,999, 10 = >€4,999.                                                                        |
| Peatland Rich Area                | The districts (Landkreise) were determined based on the provided postal codes. 102 out of 401 are defined as peatland-rich districts. | 0-1            | Not Peatland Rich Area=0<br>Peatland Rich Area=1                                                                                                                                                                                                  |

MEASURING SUBJECTIVE AND OBJECTIVE KNOWLEDGE

|                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |             |                                                                                                                                                                                         |
|-------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>AOT<br/>(actively open-minded thinking)</p>        | <p>1. "Allowing oneself to be convinced by a counterargument is a sign of good character."<br/>                 2. "People should consider evidence-based relationships that contradict their own beliefs."<br/>                 3. "People should revise their beliefs in response to new information or evidence."<br/>                 4. "Changing one's position is a sign of weakness."<br/>                 5. "Intuition is the best advice when making decisions."<br/>                 6. "It is important to stick to one's beliefs, even when there is contrary evidence."<br/>                 7. "One should ignore evidence when it contradicts one's deeply held beliefs."</p> | <p>1-7</p>  | <p>1 = Strongly Disagree, 4 = Neutral, and 7 = Strongly Agree. Reverse coding applied to questions 4, 5, 6, and 7.<br/><br/>                 AOT is the average of the seven items.</p> |
| <p>Time Preference</p>                                | <p>"How would you personally rate yourself: Are you generally an impatient person, or do you always show a lot of patience?"</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | <p>1-11</p> | <p>1 = Very impatient, 11 = Very patient.</p>                                                                                                                                           |
| <p>Risk Preference</p>                                | <p>"How would you personally rate yourself: Are you generally a risk-taking person, or do you try to avoid risks?"</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <p>1-11</p> | <p>1 = Not at all risk-taking, 11 = Very risk-taking</p>                                                                                                                                |
| <p>Environmental Protection Importance (Personal)</p> | <p>"Please assess! For me personally, environmental protection is ..."</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | <p>1-5</p>  | <p>1 = Very unimportant, 5 = Very important</p>                                                                                                                                         |
| <p>Trust in Science</p>                               | <p>"To what extent do you trust scientific results?"</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <p>1-4</p>  | <p>1 = No trust at all, 4 = A lot of trust</p>                                                                                                                                          |

CHAPTER 4

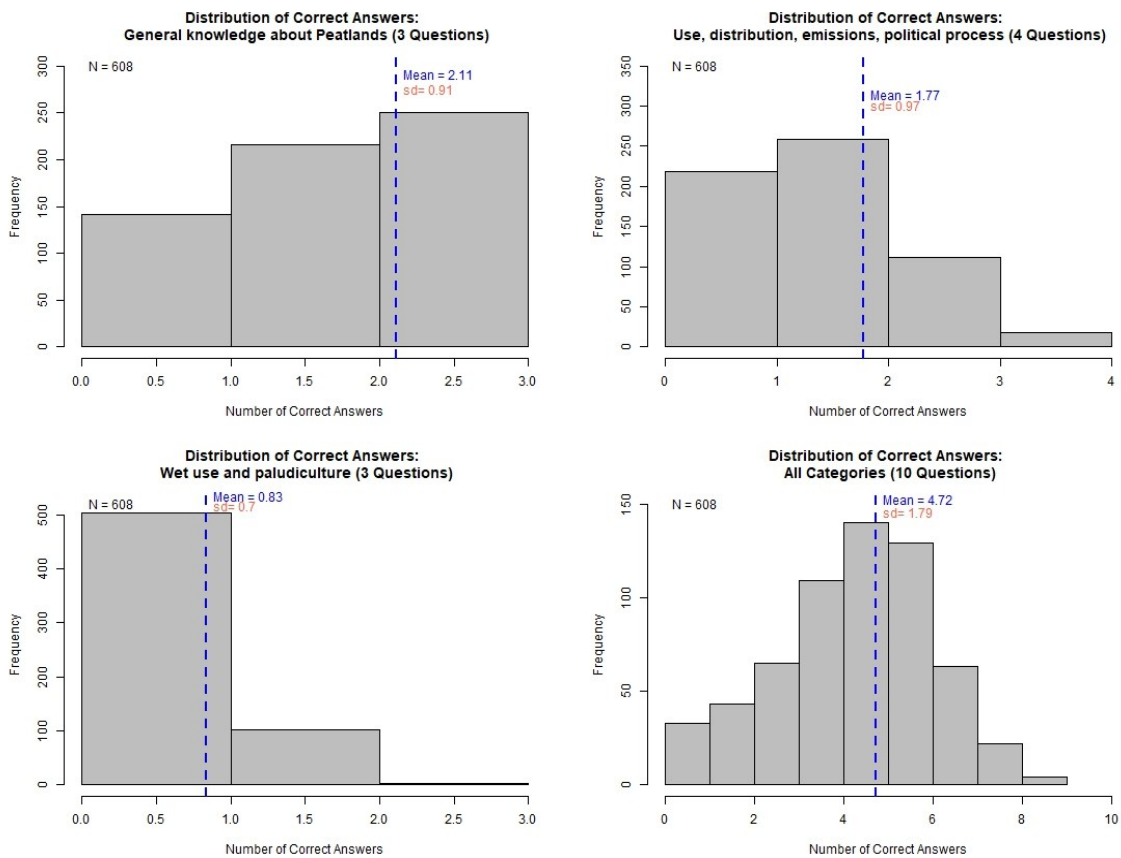
|                                 |                                                                                                                                                                           |      |                                              |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|----------------------------------------------|
| Connection to Rural Areas       | "I have a connection to rural areas because I live there, grew up there, or have close relatives/friends in rural areas."                                                 | 1-5  | 1 = Does not apply at all, 5 = Fully applies |
| Political View                  | "In politics, people often talk about 'left' and 'right' to describe different political views. Thinking about your own political views, where would you place yourself?" | 1-11 | 1 = Far Left, 11 = Far Right                 |
| Family Contribution to Drainage | "My family/ancestors contributed significantly to the drainage of land, making it suitable for agricultural use."                                                         | 0-1  | 0 = Does not apply<br>1 = Applies            |

**Source:** Own Presentation

**A2: Description of the sample**

The age of participants in our sample ranged from 18 to 74 years, with a mean age of 47.4 years. To facilitate analysis, we categorised participants into five age groups: 18-30, 31-40, 41-50, 51-60, and 60+. For comparison, the average age in Germany in 2023 was 44.6 years (Destatis, 2024a). Regarding Sex assigned at birth distribution, 49.7% of participants in the sample identified as male, and 50.3% as female, closely aligning with the general population in Germany, where 49.35% are male and 50.65% are female (Destatis, 2024b). We stick with the female-male dichotomy because of the low sample size of non-binary people ( $N = 2$ ). Non-binary people were not considered at any stage of data analysis. In our sample, 38.36% of participants possess a university entrance qualification. This is somewhat higher than in the general population of Germany, where 20.5% have a university entrance qualification (Statistisches Bundesamt, 2024). However, the large variety of people in our sample enables us to draw meaningful conclusions.

**Figure A2.1: Distribution of correct answers**



**Source:** Own Presentation.

The participants demonstrate the highest knowledge in the category of general knowledge about peatlands (Mean = 2.11). The lowest knowledge scores can be found in the category of wet use and paludiculture (Mean = 0.83). Within the category reflecting knowledge about use, distribution, emissions and political process, the scores were moderate (Mean = 1.77). The distribution of objective knowledge across all categories shows that the majority of participants fall within the moderate range, while few participants are found at the extremes of the scale (Mean = 4.72).

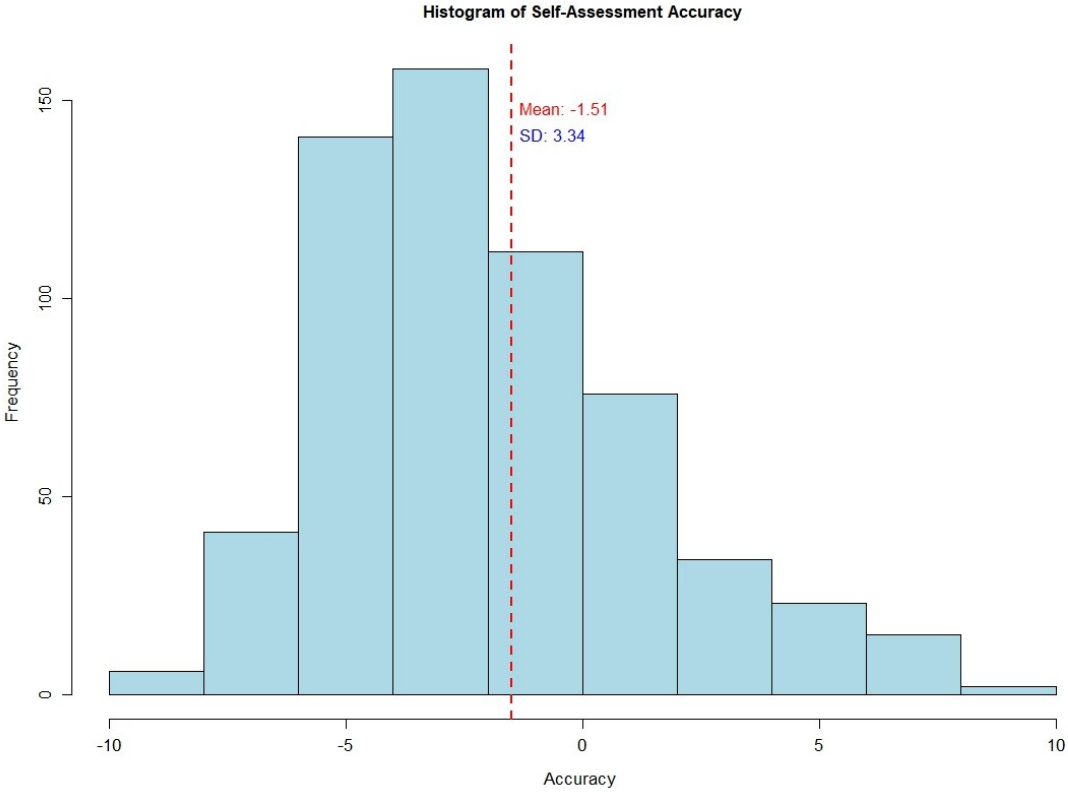
**Table A2.1: Correlation between the categories**

| Variables                                                             |                                                                       | Correlation Coefficient (r)<br>Spearman |
|-----------------------------------------------------------------------|-----------------------------------------------------------------------|-----------------------------------------|
| <b>Category 1:</b> general knowledge about peatlands                  | <b>Category 2:</b> use, distribution, emissions and political process | 0.375                                   |
| <b>Category 1:</b> general knowledge about peatlands                  | <b>Category 3:</b> wet use and paludiculture                          | 0.049                                   |
| <b>Category 2:</b> use, distribution, emissions and political process | <b>Category 3:</b> wet use and paludiculture                          | 0.124                                   |

**Source:** Own Calculation

The correlation analysis indicates that participants with a high score in category 1 tend to also have a high score in category 2, and vice versa ( $r = 0.375$ ). The category 3 is weakly correlated with the other two categories. So there seems to be a low association between knowledge about wet use and paludiculture to general knowledge about peatlands ( $r = 0.049$ ) and also to knowledge about use, distributions, emissions, and the political process ( $r = 0.124$ ).

**Figure A2.2: Histogram of self-assessment accuracy**



Source: Own Presentation.

**A3: Correlation tables****Table A3.1: Correlation values for Figure 2**

| <b>Determinants</b>                 | <b>Correlation</b> | <b>Correlation-Type</b> | <b>Category</b> |
|-------------------------------------|--------------------|-------------------------|-----------------|
| Age Group                           | 0.037              | Spearman                | Underestimation |
| Sex assigned at birth               | 0.112              | Point-Biserial          | Underestimation |
| Education                           | 0.016              | Spearman                | Underestimation |
| Income                              | -0.094             | Spearman                | Underestimation |
| Inhabitants                         | 0.078              | Spearman                | Underestimation |
| Peatland Rich Area                  | 0.011              | Point-Biserial          | Underestimation |
| AOT                                 | 0.068              | Spearman                | Underestimation |
| Risk Preference                     | -0.177             | Spearman                | Underestimation |
| Time Preference                     | 0.018              | Spearman                | Underestimation |
| Connection to Rural Areas           | -0.095             | Spearman                | Underestimation |
| Family Contribution to Drainage     | -0.006             | Point-Biserial          | Underestimation |
| Environmental Protection Importance | -0.006             | Spearman                | Underestimation |
| Trust in science                    | 0.057              | Spearman                | Underestimation |
| Political View                      | -0.065             | Spearman                | Underestimation |
| Age Group                           | -0.272             | Spearman                | Overestimation  |
| Sex assigned at birth               | -0.26              | Point-Biserial          | Overestimation  |
| Education                           | 0.190              | Spearman                | Overestimation  |
| Income                              | 0.104              | Spearman                | Overestimation  |
| Inhabitants                         | 0.193              | Spearman                | Overestimation  |
| Peatland Rich Area                  | 0.106              | Point-Biserial          | Overestimation  |
| AOT                                 | -0.340             | Spearman                | Overestimation  |
| Risk Preference                     | 0.316              | Spearman                | Overestimation  |
| Time Preference                     | 0.186              | Spearman                | Overestimation  |
| Connection to Rural Areas           | -0.039             | Spearman                | Overestimation  |
| Family Contribution to Drainage     | 0.287              | Point-Biserial          | Overestimation  |
| Environmental Protection Importance | 0.083              | Spearman                | Overestimation  |
| Trust in science                    | -0.0002            | Spearman                | Overestimation  |
| Political View                      | 0.162              | Spearman                | Overestimation  |

**Source:** Own Calculation

**Table A3.2: Correlation values for Figure 3**

| <b>Determinants</b>                 | <b>Correlation</b> | <b>Correlation-Type</b> | <b>Knowledge Type</b> |
|-------------------------------------|--------------------|-------------------------|-----------------------|
| Age Group                           | 0.283              | Spearman                | Objective             |
| Age Group                           | -0.049             | Spearman                | Subjective            |
| Sex assigned at birth               | -0.236             | Point-Biserial          | Objective             |
| Sex assigned at birth               | -0.002             | Point-Biserial          | Subjective            |
| Education                           | 0.198              | Spearman                | Objective             |
| Education                           | 0.098              | Spearman                | Subjective            |
| Income                              | 0.055              | Spearman                | Objective             |
| Income                              | 0.128              | Spearman                | Subjective            |
| Inhabitants                         | -0.059             | Spearman                | Objective             |
| Inhabitants                         | -0.002             | Spearman                | Subjective            |
| Peatland Rich Area                  | 0.069              | Point-Biserial          | Objective             |
| Peatland Rich Area                  | -0.004             | Point-Biserial          | Subjective            |
| AOT                                 | 0.395              | Spearman                | Objective             |
| AOT                                 | -0.073             | Spearman                | Subjective            |
| Risk Preference                     | 0.390              | Spearman                | Objective             |
| Risk Preference                     | -0.160             | Spearman                | Subjective            |
| Time Preference                     | 0.006              | Spearman                | Objective             |
| Time Preference                     | 0.133              | Spearman                | Subjective            |
| Connection to Rural Areas           | 0.018              | Spearman                | Objective             |
| Connection to Rural Areas           | 0.207              | Spearman                | Subjective            |
| Family Contribution to Drainage     | -0.255             | Point-Biserial          | Objective             |
| Family Contribution to Drainage     | 0.145              | Point-Biserial          | Subjective            |
| Environmental Protection Importance | 0.201              | Spearman                | Objective             |
| Environmental Protection Importance | 0.065              | Spearman                | Subjective            |
| Trust in science                    | 0.064              | Spearman                | Objective             |
| Trust in science                    | 0.202              | Spearman                | Subjective            |
| Political View                      | -0.080             | Spearman                | Objective             |
| Political View                      | 0.080              | Spearman                | Subjective            |

Source: Own Calculation

**A4: Questionnaire**

**Note:** The questionnaire was translated from German into English by the authors. Not all questions or parts of the questionnaire are the content of the analysis within the paper: “How Well are Peatlands Understood? Lessons from Measuring Subjective and Objective Knowledge”.

*Section 1: Basic Questions*

Welcome to the University of Rostock Survey!

Thank you for your interest in our survey!

We are conducting a study on perceptions and attitudes in the environmental field. The total duration is approximately 15 minutes. Please answer all questions honestly and do not skip any. Thank you!

Participation is voluntary and can be discontinued at any time. Your data will be processed anonymously and confidentially. Your anonymised data may be used in scientific publications. You have the right to delete your data at any point during the survey.

Study coordinators

Pia Sommer

University of Rostock

For questions or comments: [pia.sommer@uni-rostock.de](mailto:pia.sommer@uni-rostock.de)

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Please note that you must be 18 years or older to participate.

- **I confirm that I am 18 years old or older.**

If you agree to participate, including the data processing terms described above, please click the field below to begin.

- **Yes, I accept the terms and participate in the study.**

**1.1 How old are you?**

\_\_\_\_\_ years

**1.2 What is your gender (per birth register)?**

- Male
- Female
- Diverse/non-binary
- Not specified

**1.3 What is your highest educational qualification?**

## CHAPTER 4

- No degree
- Secondary general school certificate (Hauptschulabschluss)
- Intermediate school certificate (Realschulabschluss)
- University entrance qualification (Abitur/Fachhochschulreife)
- Bachelor's degree or equivalent
- Master's degree, Diplom, Magister, State exam
- Doctorate (PhD)

**Please enter the postal code of your primary residence.**

-----

[Internal: Allow only valid ZIP codes; create new variable for federal state.]

**Are you currently or have you previously worked in one of the following occupational fields? (Please select the field that best applies.)**

- Agriculture, forestry, animal husbandry, horticulture
- Extraction of raw materials, production, manufacturing
- Construction, architecture, surveying, building services
- Natural sciences, geography, computer science
- Transport, logistics, protection and security
- Commercial services, trade, sales, tourism
- Business administration, accounting, law, administration
- Health, social work, education and teaching
- Humanities, culture, design
- Military
- Not applicable (none of the listed professions apply)

**The following statements may apply to them to a greater or lesser extent. For each statement, please indicate the extent to which it applies to you personally.**

| Statement                                                                 | Does not<br>apply at all | Applies<br>slightly     | Applies<br>somewhat     | Applies<br>quite well   | Applies<br>completely   |
|---------------------------------------------------------------------------|--------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| I am in control of my own life.                                           | <input type="radio"/> 1  | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| If I make an effort, I will succeed.                                      | <input type="radio"/> 1  | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| Whether private or professional: my life is largely determined by others. | <input type="radio"/> 1  | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| My plans are often thwarted by fate.                                      | <input type="radio"/> 1  | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |

### *Section 2: Personal Traits*

**2.1 How do you rate yourself personally: are you generally a risk-taker or do you try to avoid risks?**

**Scale: 0–10**

0 - Not at all willing to take risks | **10** – Very willing to take risks.

**2.2 How do you rate yourself personally: are you generally an impatient person or someone who is always very patient?**

**Scale:** 0–10

0 - very impatient | **10** – very patient.

*Section 3: Peatland-Quiz*

**Below, we ask you to take part in our “quiz” on the subject of peatlands! Your opinions are of great importance to us. We therefore ask you to refrain from using aids. Not all questions are easy to answer, as the quiz also contains some difficult questions. Please do not let this discourage you!**

**Please note: Please tick all the answer options that you think are applicable.**

**Unless otherwise stated, this means that no answer, one answer, several answers or all answers can be ticked.**

**Have fun!**

How do you rate yourself personally: How well do you know the subject of peatlands?

**Scale:** 0–10

**0** – Very poor | **10** – Very good

[Internal comment: The categories were presented on a slider.]

**[Internal comment:** Page break]

**[Internal comment:** The first part of the quiz was about: General knowledge about peatlands]

An area is generally referred to as a peatland when...

**Options (select all that apply):**

- ...it is a shallow lake.
- ...there is a layer of peat in the soil.
- ...it was historically considered a mystical place for nocturnal rituals and secret dances.
- ...it has a particularly high mosquito population.

**[Internal comment:** Page break]

## CHAPTER 4

Assess which of the following options apply to intact peatlands (i.e., peatlands in their natural state).

**Options (select all that apply):**

In order to preserve intact peatlands...

- ...peat soils should be kept dry.
- ...peat soils should be kept wet.
- ...peat soils should be fertilised.
- ...peat soils should be ploughed.

Now, let's consider intact peatlands (i.e., in their natural state) in Germany. Which of the following statements do you consider accurate?

**Options (select all that apply):**

Intact peatlands...

- ... are dangerous places that should be avoided.
- ...pose an additional risk for flooding during heavy rainfall events.
- ...act as carbon stores and can absorb CO<sub>2</sub> from the atmosphere.
- ...are peatlands that no longer form peat.

**What do you think is true about intact peatlands?**

- Peatlands filter water and thus improve water quality.
- Peatlands store only saltwater.
- Peatlands are especially suitable for grazing cattle.
- Peatlands are found mainly in forests.

[Internal comment: The second part of the quiz was about: Use, Distribution, Emissions, Political Process]

**In Germany, peatlands have recently been recognised as politically significant. Which arguments do you think apply?**

Intact peatlands (i.e. peatlands in their natural state) are considered worthy of protection in Germany because they...

- ... are an essential component of Germany's national defence.
- ... are an important raw material source for natural cosmetics.
- ... are a key component in climate protection.
- ... are sacred places for nature religions.

[Internal comment: Page brake]

What share of peatland area in Germany is used for agriculture (cropland and grassland)? [not included in quiz analysis]

(Only one answer is correct.)

- Nearly all peatland area
- Slightly less than half
- Almost three-quarters
- Almost none

Attention Check

In surveys like this one, there are sometimes participants who do not read the questions carefully, which can lead to random responses.

To demonstrate that you are paying attention, please select **elephant** and **horse** in the next question.

**What is your favourite animal?** (Multiple answers allowed)

- Dolphin
- Squirrel
- **Elephant**
- Dog
- Cat
- **Horse**
- Penguin
- Budgerigar
- Another animal

[Note: This is the 'Attention Check': People who did not mark the correct box were removed from the data set]

**How are peat soils (intact peatlands and drained peatlands) geographically distributed in Germany?**

Please select the option you consider correct.

*The majority of the peatlands are...*

**Options:**

- ...in the Alps and the Black Forest, i.e., in Bavaria and Baden-Württemberg.
- ...in the northern federal states (Lower Saxony, Schleswig-Holstein, Mecklenburg-Western Pomerania, and Brandenburg).
- ...in federal states with low mountain ranges (Saxony, Thuringia, Hesse, Rhineland-Palatinate, Saarland, and North Rhine-Westphalia).
- ...around the Ruhr area (North Rhine-Westphalia).

**Now we have a question about a rather technical term:**

**Melioration describes, among other things ...**

- the targeted establishment of nature conservation areas, e.g. peatland conservation areas
- the implementation of voluntary biodiversity measures by farmers on, e.g. peatlands.

- the historical implementation of large-scale peatland drainage projects
- the commercial use of peatland products in natural cosmetics

[Internal: Randomise order of items, allow multiple answers].

**What do you estimate, which type of use causes the largest share of greenhouse gas emissions from peat soils in Germany (considering both intact and drained peatlands)?**

Options:

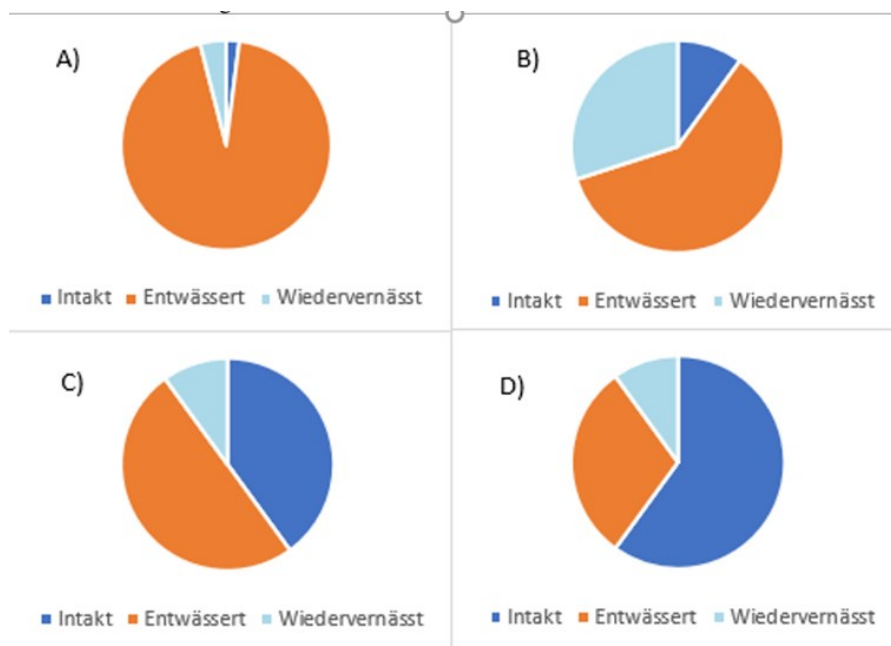
- Peat extraction for horticulture.
- Conventional agricultural use of peat soils.
- Forestry on peat soils.
- Urban settlements and infrastructure on peat soils.

[Internal: Randomise order of items, allow only one answer.]

[Internal comment: Page break]

The following question concerns the ratio of intact peatlands (i.e., in their natural state), drained peatlands (i.e., peatlands that have been drained), and rewetted peatlands (i.e., previously drained peatlands where the water level has been raised close to the soil surface) in Germany. Below, you see four figures. The circle represents the total area of peat soils in Germany. Intact, drained, and rewetted peatlands are shown in different colours.

**Which figure do you think best reflects the situation in Germany?**



[Internal comment: Page break]

[Internal comment: The third part of the quiz was about: Wet Use and Paludiculture]

**Please assess the following statement:**

“Agricultural used peatlands that are rewetted to reduce emissions can no longer be used for agriculture after rewetting.”

Options:

- Agree.
- Disagree.

[Internal comment: Page break]

**Which of the following products suggests a production that is more likely to preserve the peatlands (i.e. the peat layer is preserved and does not decompose) or more likely to damage the peatlands (i.e. the peat layer gradually degrades/decomposes)?**

For each product, please indicate whether you consider it to be peatland-preserving or peatland-damaging.

|                                                           | Preserving peatland     | Damaging peatland       |
|-----------------------------------------------------------|-------------------------|-------------------------|
| Conventional peat potatoes                                | <input type="radio"/> 1 | <input type="radio"/> 2 |
| Organic peat potatoes                                     | <input type="radio"/> 1 | <input type="radio"/> 2 |
| Sustainable building materials made from cattail and reed | <input type="radio"/> 1 | <input type="radio"/> 2 |
| Potting soil containing peat                              | <input type="radio"/> 1 | <input type="radio"/> 2 |
| Energy maize for bioenergy on peatlands                   | <input type="radio"/> 1 | <input type="radio"/> 2 |
| Nature conservation meat from water buffalo               | <input type="radio"/> 1 | <input type="radio"/> 2 |
| Organic peatland cow's milk                               | <input type="radio"/> 1 | <input type="radio"/> 2 |
| Conventional peatland cow's milk                          | <input type="radio"/> 1 | <input type="radio"/> 2 |

[Internal: Randomise order of items].

[Internal comment: Page break]

**Which of the following examples describes a change from a peat-damaging use (i.e., causing the gradual decomposition of the peat layer) to a peat-preserving use (i.e., maintaining the peat layer and preventing its decomposition)?**

Options (select all that apply):

- Conversion of a conventionally managed field with low water levels to an organically managed field with low water levels.
- Conversion of a meadow with low water levels to a forest with low water levels.
- Conversion of a field with low water levels to a cattle pasture with low water levels.
- Conversion of fallow land with low water levels to a water buffalo pasture with high water levels.

**What do you think: Which products or raw materials can originate from rewetted peat soils?**

Options (select all that apply):

- Sunflower oil from organic farming.
- Cattail for construction materials.

- Carrots grown on peat soil, so-called “peat carrots.”
- Mosses as a peat substitute for potting soil.

[Internal comment: Page break]

**The first part of the questionnaire has now been completed with the quiz. What percentage of the quiz questions do you think you answered correctly?**

---text box---%

Would you like to have a PDF with the information about the correct answer options from the quiz at the end of the questionnaire?

- Yes
- No

[Internal comment: Page break]

**The following statements may apply to you to a greater or lesser extent. For each statement, please indicate how much the statement applies to you.**

Scale: 1=Does not apply at all, 2= Does not apply very much, 3= Applies somewhat, 4= Applies somewhat, 5= Applies

- It has happened before that I have taken advantage of someone.
- Even when I'm stressed myself, I always treat others in a friendly and courteous manner.
- Sometimes I only help someone if I can expect something in return.
- I always remain factual and objective in arguments.
- I have sometimes thrown garbage in the countryside or on the street.
- When I talk to someone, I always listen carefully.

[Internal comment: Page break]

Now let's look at a few more general questions about the environment.

**How true or false do you find the following statements?**

[Scale: 1=Not true at all; 2= Rather not true; 3= Partly/partly true, 4= Rather true; 4=Fully true]

- Forests make an important contribution to climate protection.
- Climate change is decisively influenced/made by humans.

**Please evaluate!**

- For me personally, environmental protection is

[DROP-DOWN]

[Internal: Drop-down list with possible answers: Very unimportant, Unimportant, Partly/partly, Important, Very important]

- I think that for society is environmental protection [DROP-DOWN]

[Internal: Drop-down list with possible answers: Very unimportant, Unimportant, Partly/partly, Important, Very important]

[Internal comment: Page break]

**Do the following statements apply to you or not?**

I am of the opinion that the drainage of peatland used for agriculture should be maintained because ...

[Scale: 1=Applies, 2= Does not apply]

- my family/ancestors did a lot to drain the land so that it could be used for agriculture.
- it is economically important for agriculture to continue draining the land.
- the energy and transport sector should first reduce emissions before peatlands are rewetted.
- the areas in Germany are needed to ensure food security.

[Internal: Randomise the order of the items.]

**What is important to you when deciding what food to buy?**

|                     | Not at all important    | Rather not important    | Moderately important    | Rather important        | Very important          |
|---------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| Fair trade          | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| Climate protection  | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| Organic cultivation | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| Regionality         | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| Animal welfare      | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| Price               | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |

[Internal: Randomise the order of the items. Each item should be answered.]

[Internal comment: Page break]

**When I think of sustainable and climate-friendly agriculture, the first thing I think of is:**

.....[Text box for writing].....

[Internal: Open question]

[Internal: Page break]

**Please name three measures that you believe agriculture can best contribute to climate protection**

1 .....

2 .....

3 .....

[Internal: Open question, three answer fields, each field must be filled in]

[Internal: Page break]

**There are many natural carbon storages in nature, i.e. they can absorb CO<sub>2</sub> from the air and store it. The preservation of certain ecosystems is therefore considered to play an important role in climate protection.**

**Which of the ecosystems listed do you think provides the largest carbon store per hectare? Please rank them, with 1 being the largest and 4 the smallest carbon store.**

- Forest
- Grassland (i.e. pastures and meadows)
- Peatland
- Coastal dunes

[Internal: Must be sorted in order from the participants]

**Now the topic is peatland rewetting, in which drained peatland sites are restored to their wet state.**

**To what extent do you agree or disagree with the following statements?**

|                                                                                                                   | Do not agree at all     | Agree a little          | Agree somewhat          | Agree quite a bit       | Agree completely        |
|-------------------------------------------------------------------------------------------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| In my opinion, more should be done politically to protect the climate.                                            | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| The rewetting of peatlands is important for climate protection.                                                   | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| There should be a fixed date in the near future by which all areas that can be rewetted should also be rewetted.  | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| The rewetting of peatlands used for agricultural purposes should be carried out exclusively on a voluntary basis. | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| The rewetting of peatlands places high economic demands on farms.                                                 | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |

|                                                                                                               |                         |                         |                         |                         |                         |
|---------------------------------------------------------------------------------------------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| The financial burden of large-scale rewetting of peatlands should be borne by society as a whole.             | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| The financial burden of large-scale rewetting of peatlands should be borne by the richest members of society. | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |
| The financial burden of large-scale rewetting of peatlands should be borne by the affected farms themselves.  | <input type="radio"/> 1 | <input type="radio"/> 2 | <input type="radio"/> 3 | <input type="radio"/> 4 | <input type="radio"/> 5 |

[Internal: Randomise order of items].

[Internal: Page break]

**What concerns do you have when you think about peatland rewetting?**

.....[Text box for writing].....

[Internal: Open question]

**Please evaluate!**

**Peatland protection has received financial support over the last 5 years ....**

- greatly reduced
- reduced
- has remained the same
- expanded
- greatly expanded
- [Internal: Page break]

[Internal: Page break]

**Now the topic is the drainage of peatlands in comparison to the coal phase-out**

The cessation of peatland drainage is increasingly discussed in public communication as a society-wide transformation process that must be politically managed. A well-known example of such a politically organised transformation in recent history is the phase-out of coal mining and coal-fired electricity generation (coal phase-out).

**Please rate the following statement based on your personal opinion using the scale below:**

*"In my opinion, the cessation of peatland drainage is of less / greater societal importance for the affected regions compared to the coal phase-out."*

[Scale from 0 to 10]

0□ = The cessation of peatland drainage is less important than the coal phase-out

1□

2□

3□

4□

5□ = Both are about equally important

CHAPTER 4

6

7

8

9

10  = The cessation of peatland drainage is more important than the coal phase-out

*"In my opinion, the cessation of peatland drainage is of less / greater societal importance for the affected people compared to the coal phase-out."*

[Scale from 0 to 10]

0  = The cessation of peatland drainage is less important than the coal phase-out

1

2

3

4

5  = Both are about equally important

6

7

8

9

10  = The cessation of peatland drainage is more important than the coal phase-out

**Please give your assessment!**

**The media provide information on the topic of peatland rewetting or peatland protection:**

Far too little

Somewhat too little

Appropriate

Somewhat too much

Far too much

**To what extent do you have trust in scientific results**

No trust at all

Appropriate

Somewhat too much

Far too much

[ **Internal:** Page break

**Would you like to be informed on products if they have been produced in a peat-friendly way?**

- I definitely do not want to
- I would rather not
- I don't care
- I would rather
- I would definitely like to

**Please indicate: The following topics related to peatlands would interest me**

[Scale: Does not apply at all; Rather does not apply; Rather applies; Fully applies]

- Tourism
- Use and spread of peat soils in my local area
- Construction materials from plants grown on rewetted land
- Costs of rewetting
- Climate protection
- Photovoltaic systems on rewetted areas
- Agriculture
- Mosquito issues
- Potential uses of rewetted land
- Political process
- Biodiversity
- Scientific findings
- Rewetting projects in my region
- Nature conservation in peatlands
- The following topic was not included, but would also interest me in relation to peatland: .....[Text box for writing].....

[Internal: Randomise the order of the items. Each item should be answered on a scale from Does not apply at all to Fully applies - see above.]

**Please assess: How true do you find the following statements?**

[Scale: 1= Does not apply at all; 2= Applies a little; 3= Applies somewhat; 4= Applies quite a bit; 5= Fully applies]

- I cultivate a garden or enjoy gardening.
- I have a connection to rural areas because I live/grew up here, or have close relatives/friends in rural areas

[Internal: Randomise order of items].

[Internal: Page break]

**Please indicate your agreement or disagreement with the following statements.**

[Scale: 1=Does not apply at all; 2= Does not apply; 3=Rather not apply; 4= Neutral; 5= Rather agree; 6= Agree; 7= Fully agree]

|           |   |   |   |   |   |   |   |
|-----------|---|---|---|---|---|---|---|
| Statement | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|-----------|---|---|---|---|---|---|---|

## CHAPTER 4

Allowing oneself to be convinced by a counterargument is a sign of good character. 1 2 3 4 5 6 7

People should consider evidence that is not consistent with their own beliefs. 1 2 3 4 5 6 7

People should correct their beliefs in response to new information or evidence. 1 2 3 4 5 6 7

Changing one's standpoint is a sign of weakness. 1 2 3 4 5 6 7

Intuition is the best advice when making decisions. 1 2 3 4 5 6 7

It is important to stick to one's beliefs even when contrary evidence exists. 1 2 3 4 5 6 7

One should disregard evidence if it contradicts one's firm beliefs. 1 2 3 4 5 6 7

[**Internal:** randomise order of these seven items.]

[**Internal:** Page break]

[Note: Here started an experiment about communication and willingness to pay. The experiment is not part of the paper analysis.]

[Intern: Experiment: Communication (Experiment I + survey)  
Information intervention (random assignment of people to scenarios)  
150 participants per group = 600 participants  
4 groups (benchmark, T1, T2, T3)]

### Benchmark

There is to be a new national peatland protection strategy. The rewetting of peatlands is to be part of this strategy.

#### T1

There is a new national peatland protection strategy. Part of this is the rewetting of peatlands. The rewetting of peatlands saves CO<sub>2</sub> emissions. The higher the level of ambition, the greater the reduction in CO<sub>2</sub> emissions.

#### T2

There is a national peatland protection strategy. Part of this is the rewetting of peatlands. The rewetting of peatlands generates currently unknown costs for the national budget. The higher the level of ambition, the higher the costs for the national budget.

#### T3

There is a national peatland protection strategy. Part of this strategy is the rewetting of peatlands. The rewetting of peatlands saves CO<sub>2</sub> emissions and generates costs for the national budget that are currently unknown. The higher the level of ambition, the greater the reduction in CO<sub>2</sub> emissions and the higher the costs for the national budget.

[Internal: End of randomisation, now again for everyone.]

**Imagine you work in politics and have to make a decision. Which path would you vote for?**

**Choose a rewetting path for the national peatland protection strategy.**

- Path 1: Less ambitious
- Path 2: Moderately ambitious
- Path 3: Very ambitious

**Now, put yourself in the shoes of a private individual. How much would you be prepared to donate anonymously each year to support peatland rewetting?**

.....[Text box for writing] €

**How do you see it: How much should each person taking part in the survey donate?**

..... €

**How much do you think the other participants actually donate on average?**

..... €

[Internal: Euro amounts with 2 decimal places; critical limit: > 100 000€]

[Internal: Page break]

**To what extent did the information from this survey change their personal willingness to donate to peatland rewetting?**

- Reduced
- Not at all
- Increased

[Internal: Page Break]

Now you see various policy objectives. Which would be particularly important to you in the context of a national peatland protection strategy? You can express your appreciation in the form of points.

**You have a total of 100 points. Please assign these points to the following categories. You can divide the points up as you wish according to how much you value them.**

[Internal: Participants must assign points from 0 to 100 to the following items. A total of exactly 100 points must be awarded. If there are fewer or more points, a message appears that exactly 100 points must be allocated. The order of the items is randomised.]

- Measures to protect biodiversity
- to reduce emissions from peatlands as quickly as possible
- Rewetting should be completely voluntary for the affected farmers and landowners
- Advice and training for farmers on rewetting and wet use.
- Comply with climate protection targets (climate neutrality by 2045)
- Rewetting should be socially acceptable for the affected regions (i.e. the major changes should be softened by additional funding from the federal budget).

- Planning security should be created for affected farmers and landowners for the next 20 years
- The protection of intact peatlands

[Note: At this point, five questions were asked on the topic of biodiversity, which were not asked in connection with the topic of peatland and rewetting and are not or will not be part of this evaluation.]

**How many inhabitants does your main place of residence have (approximately)?**

- 1  Under 2,000 inhabitants
- 2  2,000 to under 5,000 inhabitants
- 3  5,000 to under 20,000 inhabitants
- 4  20,000 to under 50,000 inhabitants
- 5  50,000 to under 100,000 inhabitants
- 6  100,000 to under 500,000 inhabitants
- 7  500,000 inhabitants and more inhabitants

**If you take all incomes together: What is the net monthly household income of all household members today?**

Please enter the monthly net amount, i.e. after deduction of taxes and social security contributions. Please include regular payments such as pensions, housing benefit, child benefit, BAföG, maintenance payments, etc.!

If not known exactly: Please estimate the monthly amount.

|                 |                          |
|-----------------|--------------------------|
| Under 1000 €    | <input type="radio"/> 1  |
| 1000 € – 1499 € | <input type="radio"/> 2  |
| 1500 € – 1999 € | <input type="radio"/> 3  |
| 2000 € – 2499 € | <input type="radio"/> 4  |
| 2500 € – 2999 € | <input type="radio"/> 5  |
| 3000 € – 3499 € | <input type="radio"/> 6  |
| 3500 € – 3999 € | <input type="radio"/> 7  |
| 4000 € – 4499 € | <input type="radio"/> 8  |
| 4500 € – 4999 € | <input type="radio"/> 9  |
| Over 4999 €     | <input type="radio"/> 10 |

**Now, let's look at the composition of your household. How many people live in your household in total? Please include yourself and any children.**

..... (Internal: Dropdown 1, 2, 3, 4, 5, 6 or more)

**What is your family status?**

- Single
- Married or registered same-sex civil partnership
- Divorced or registered same-sex civil partnership dissolved
- Widowed or registered civil partner (same-sex) deceased

**In politics, people often talk about “left” and “right” when it comes to characterising different political views. When you think of your own political views, where would you categorise them?**

**[Scale: 1= Very left; 10= Very right]**

**[Internal: Page break]**

**Here you have the opportunity to download the PDF with the correct solutions from the quiz [LINK]**

**Please click on the button below to complete the survey.**



## CHAPTER 5

### SYNTHESIS AND OUTLOOK: DISCUSSION, CONTRIBUTIONS, AND FUTURE RESEARCH DIRECTIONS



## 1. Main results and interlinkage of the three papers as a contribution to answering the research question

The dissertation examines the research question: ‘How can rewetting of agriculturally used peatlands in Germany be shaped as a sustainable transition process in line with climate targets?’. In the following, I outline the most important results and interlinkages of the three papers.

**Paper 1** examines peatland rewetting as a transition of a socio-technical regime and concentrates on the process of terminating the no longer desired and unsustainable practice of peatland drainage by spelling it out as an exnovation governance problem. By applying exnovation as a conceptual perspective for governance, all four exnovation governance dimensions (discourse, policy instruments, agency, and justice) should be addressed in a coherent policy process to ensure a sustainable transition in a just way. Understanding the peatland drainage phase-out as a socio-technical transition enables us to compare the peatland drainage phase-out to other socio-technical transitions and to learn from them. In Germany, the coal phase-out is a very prominent example of a governed transition process of a socio-technical system to phase out an unsustainable practice and technology to reduce emissions. **Paper 2** shows the similarities and dissimilarities between the sectors affected by the coal phase-out and the peatland drainage phase-out, respectively. This comparison deepens the understanding of the multidimensional impacts of a peatland drainage phase-out and further underlines the understanding as a socio-technical transition as introduced in **Paper 1**. The in **Paper 2** derived justified political budget for peatland rewetting ranges between 13.8 and 16 billion €, assuming a 2 % discount rate, quantifying a financial scale compared to the coal phase-out governed as a socially acceptable and just transition. As mentioned in **Paper 1** and **Paper 2**, the peatland drainage phase-out should be seen as an overall societal task. Due to an upcoming financial burden and political measures to govern this transition in a just and socially acceptable way, the support and acceptance of the public are necessary. As knowledge is one important aspect in shaping environmental concern and public support for climate protection, understanding knowledge is also an important component in shaping the peatland drainage phase-out as a socially acceptable transition. Without broad social support, resistance could delay or even hinder the implementation of rewetting measures. **Paper 3** focuses on the nationwide knowledge level about peatlands and peatland rewetting and elaborates on existing patterns. The results reveal a gap between objective and subjective knowledge about peatlands and peatland rewetting. It can also be shown that individuals with low levels of objective knowledge tend to overestimate their knowledge, whereas those with high levels of objective knowledge

are more likely to underestimate theirs. This pattern reflects the Dunning–Kruger effect. As supplemental descriptive analysis in the discussion (see Section 2.3.2) can show, there is an openness for more information, and both the media and companies could play a greater role in providing information. With regard to the topics of interest among survey participants, it can be concluded that communication strategies and information campaigns should focus on practical aspects such as utilisation options, local projects, scientific findings, and climate and nature conservation, as these generate the most interest.

## **2. Discussion of the individual papers**

In this section, I discuss each paper individually. While the discussion draws on the key findings of the paper, it also expands beyond them by addressing additional dimensions and introducing new perspectives. In the discussion of Paper 3, I will further present and integrate additional survey results that were not included in the main analysis.

### **2.1 Paper 1: Peatland rewetting as drainage exnovation – A transition governance perspective**

#### *2.1.1 Key findings*

Spelling out large-scale peatland rewetting as an exnovation process highlights that rewetting, as part of a transition, should also be understood as the deliberate termination of drainage. This perspective draws attention to the systemic nature of change required to achieve substantial GHG emission reductions in agriculture and land use. The paper proposed four dimensions for an exnovation governance perspective: discourse, policy instruments, agency, and justice. Based on the conceptual literature on exnovation, existing policy recommendations are structured along the four dimensions and assign exemplary intervention points from the rewetting literature to the exnovation concept. Based on this, the paper shows that by applying exnovation as a conceptual perspective for governance, all four dimensions should be addressed in a coherent policy process to ensure a just transition. Further, the paper can show in a first step that the existing literature already addresses aspects from all four dimensions within research and policy recommendations and understands the multidimensionality of rewetting governance. In a second step, the paper analyses how the four dimensions are considered by the National Peatland Protection Strategy (BMUV, 2022) and the Federal-Länder-target agreement from 2021 (BUND-LÄNDER, 2021). These two documents are used as representatives of the status quo in terms of the national targets, policy design and governance process. On this basis, the paper shows that the complexity of and necessity to harmonise existing guidelines and

regulations in the interests of rewetting is understood, and some relevant aspects are addressed within all four dimensions. However, the paper also highlights several obstacles. Firstly, a clearly defined termination date with a rewetting pathway compatible with the Paris Agreement is missing. Secondly, the envisaged approaches remain within the framework of voluntarism. Thirdly, control policies are initially excluded as instruments to exert economic pressure on peatland drainage. Finally, a roadmap for socio-economic adaptation and socio-technical aftercare to facilitate a just transition process is also missing.

### *2.1.2 Critical discussion*

#### Exnovation governance approach

Within sustainable transition research, it is increasingly recognised that sustainable transitions require policies to phase-out unsustainable technologies and practices. (Fossati, 2023; Kivimaa and Kern, 2016). Feola et al. (2021) state that in the science of socio-technical and sustainable transitions, it has long been assumed that the disruption of the existing socio-technical regime occurs automatically through innovation. As a result, this disruption has remained an under-theorised field within transition research. Fossati et al. (2023) contend that it is now widely recognised that promoting sustainable innovations requires targeted policies and measures to actively phase-out, destabilise, and reduce reliance on unsustainable technologies and practices. Various concepts have been introduced to describe the mechanisms behind these processes, resulting in a diverse set of terms (cf., Bils and Töpfer, 2024; Frank and Schatz, 2022).

The paper opts for the exnovation governance approach as a concept to describe the destabilisation of socio-technical systems (David and Gross, 2019; David, 2018; 2017; Heyen et al., 2017; Arnold et al., 2015), since it addresses policy mixes (Kivimaa and Kern 2016) and intervention points (Kanger et al., 2020) for transitions (cf., Fossati et al., 2023) as a concept from transition governance research. There are other studies dealing explicitly with exnovation governance (e.g., Fossati et al., 2023; Heyen et al., 2017 and David, 2015 have already done so). Ziegler et al. (2021) and Ziegler (2020) have discussed the cessation of peatland drainage as a case of exnovation in connection with paludiculture as innovation. Heyen et al. (2017) justify the need for politically organised exnovation with the existing time pressure to reduce emissions. They underline that the exnovation process should start early and define clear goals and a time frame to ensure planning security for companies, workers, consumers, infrastructure planning and education. These measures and benefits are already called for in peatland rewetting research (see for examples: Wichmann and Nordt, 2024; Chen et al., 2024; Chen et al., 2023; Nordt et al., 2022; Schäfer et al., 2022; Wichmann et al., 2022; Nordt et al., 2022;

Wiegmann et al., 2022; Grethe, 2021; Tanneberger et al., 2021; Tanneberger et al., 2020; Ekardt et al., 2020; Schäfer and Yilmaz, 2019; Abel et al., 2019; Osterburg et al., 2018; Regina et al., 2016; Bonn et al., 2014). By analysing large-scale rewetting in Germany as an exnovation governance process, Paper 1 adds another example to sustainable transition governance research and theoretically underpins existing policy proposals for large-scale rewetting in Germany.

Assuming that the perception of rewetting peatlands as a far-reaching transition process becomes more widely accepted, could be expected that the term ‘exnovation’ would increasingly be used to describe the process and its governance. Examples that have already taken up this term in the context of peatland rewetting: Meyer-Jürshof et al. (2025), Seidel et al. (2024), Ziegler et al. (2021) and Ziegler (2020). As both the scientific discourse on exnovation as a governance approach and the framing of rewetting as a sustainable transition are emerging fields of research, this paper can contribute to both areas.

#### Transferability (other countries, administrative levels, industries)

The paper focuses on drained peatlands under agricultural use in Germany and explores how this issue can be governed as an exnovation problem. While this national focus allows for in-depth analysis, it would also be valuable to examine the situation at the EU level as well as within individual federal states, as the study is limited to the case of Germany. However, the exnovation governance approach can also support the discourse on rewetting in other peatland-rich countries. Here, of course, it must be taken into account that the narratives regarding peatland drainage, e.g. in Europe, are very different. While, e.g. in Germany and the Netherlands, drainage has primarily occurred for agricultural purposes and continues to do so, in Finland and Sweden, for example, drainage for forestry is dominant, and in the Baltic states, peat extraction for horticulture. Some European countries (e.g. Finland, Ireland, and Sweden) also have a historical tradition of peat as an energy source (cf., Räsänen et al., 2023). Furthermore, in some regions (in Europe, e.g. northern Finland), the interaction and integration of indigenous people and their knowledge is also an aspect to consider for rewetting and peatland protection (Austin et al., 2025; Yale Environment 360, 2023). These historical developments have established different narratives of socio-economic aspects than those we have specifically considered in Paper 1 (e.g. Banerjee and Schuitema, 2022; Paoli et al., 2022; Buschmann et al., 2020; Albrecht, 2018; Arnalds et al., 2016; Byg et al., 2016).

#### Innovation – Exnovation nexus

The proposed framework identifies dimensions of exnovation processes that have not yet been sufficiently addressed and enables comparisons between different cases of deliberate decline.

Given the prevalent innovation bias, it aims to shed light on the often-overlooked flipside of transition—the deliberate phase-out of unsustainable practices. The paper with its focus on exnovation does not want to diminish the importance of innovation (e.g. Geels. et al., 2017). To fully understand the transition process, it would be beneficial to further explore the innovation-exnovation nexus, as, e.g. David (2017) has done for the German energy transition policy mix.

The paper emphasises the added value of explicit exnovation governance for analytical clarity, it also recognises that terminating peatland drainage and supporting alternative innovations - such as paludiculture, peatland-PV or CO<sub>2</sub>-markets - are closely interconnected. While the paper mentions innovations, its key contribution lies in emphasizing the various aspects and challenges associated with the active phase-out of peatland drainage and highlighting termination as a central element of governance strategies for transformative and systemic change in agricultural practice.

#### Windows of opportunity

Ziegler (2020) also mentions the window of opportunity that arose in the course of German reunification, when Michael Succow and other conservationists seized the opportunity to support nature conservation and rewetting. In line with Frank et al. (2024), this paper argues that focusing on understanding change in terms of the window metaphor may not help to understand the incremental nature of transitions. The possibility of a window of opportunity does not replace the need for governance and a strategy to disrupt unsustainable systems. Of course, a window of opportunity could significantly influence the process of rewetting, but policymakers should not rely on it, for there is no guarantee that such windows of opportunity will even be recognised as such.

#### Socio-technical vs. socio-ecological approach

Lonkila et al. (2024) combine the just-transition approach with deliberate destabilisation by analysing the phasing out of the agricultural use of peatlands and the use of peat as an energy source in Finland. This study considers peatland utilisation and drainage as a socio-technical regime, as does this dissertation. Other studies, however, define peatland drainage as a socio-ecological system (e.g. Chen et al., 2024; Wichmann and Nordt, 2024; Buschmann et al., 2020). The socio-technical and socio-ecological approaches are both based in the transition research. The socio-ecological approach builds on insights from biology, ecosystem services, ecology and adaptive governance. According to Loorbach et al. (2017), the socio-ecological perspective addresses issues such as biodiversity and nature, nature-based solutions and ecosystem services, climate resilience and the role of adaptive governance. Ostrom (2019) even describes that every

resource used by humans is part of a complex, socio-ecological system. The socio-technical approach is used by many transition researchers to study transitions where socio-technical regimes have evolved around dominant technologies and are the subject of transitions (Loorbach et al., 2017).

For the case of phasing out peatland drainage for agricultural use, the concept of a socio-technical system was chosen in this dissertation as it is a fundamental concept in the transition literature to emphasise the interplay of technology and society that creates (economic) path dependencies. However, some approaches integrate the socio-technical and socio-ecological approaches into one framework - a socio-techno-ecological approach, for example (Anderson et al., 2024). Here, further research in the context of transition research using peatland rewetting as a case study could be fruitful for both transition research and research on peatland rewetting approaches and governance.

### Reflections on the method

Within the paper, the four categories (discourse, policy instruments, agency, and justice) are based on the literature and not derived from an existing definition. It could, therefore, be expanded to include further dimensions, or individual dimensions could be renamed and further summarised. One limitation of the paper is that it uses two policy strategies as a proxy for the status quo of Germany's rewetting strategy. This analysis is limited because the peatland-rich federal states also have their peatland rewetting strategies on a state level (Nitsch and Schramek, 2021). A further limitation is that it focuses on national governments as the main drivers of exnovation, while sustainability transition research often takes a more bottom-up perspective (Turnheim and Sovacool, 2020) since socio-technical change is not neatly manageable and fully controlled by central governments alone.

## **2.2 Paper 2: Deriving a justified budget for peatland rewetting – Lessons from the coal phase-out**

### *2.2.1 Key findings*

The impact of large-scale rewetting cannot be limited to the business level, but must also take socio-economic, historical and cultural aspects into account.

Using Germany as a case study, it is investigated whether the German coal phase-out can serve as a 'blueprint' for peatland rewetting as peatland drainage phase-out of agriculturally utilised peatlands, using six categories (politics, economy, society, technology, environment and law). The comparison highlights the deep integration of peatland drainage in agriculture as a socio-technical regime. Since rewetting represents a paradigm shift affecting social, cultural, and

political dimensions, government intervention is essential. To govern the transition as a multidimensional approach in line with the demand for a socially acceptable and just transition for peatland rewetting, the phase-out approach could be well suited to end peatland drainage, as it has been for the coal phase-out.

The paper suggests that the current pace of rewetting is too slow in comparison to a rewetting path following the Paris Agreement and would create an area gap of about 560,000 ha and a resulting CO<sub>2</sub> emission gap of 84.6–148 Mt CO<sub>2</sub> by 2029. Peatland drainage phase-out and coal phase-out, are socio-technical transitions which require governmental intervention and a guided-level perspective. For a governed peatland drainage phase-out on agriculturally used land in Germany, which is 1.5°C compatible, a politically justified total budget between 13.8 and 16 billion € is determined. The exploratory calculation is based on a socially acceptable reduction in CO<sub>2</sub> emissions comparable to the phase-out of coal.

### *2.2.2 Critical discussion*

#### PESTLE analysis: peatland rewetting as a socio-technical transition

The PESTLE analysis highlights that the current economic, political, social, and legal conditions continue to favour peatland drainage. As a result, relying on a market-driven exit supported solely by voluntary funding schemes for rewetting is unlikely to be sufficient to meet established emission reduction targets. Therefore, political design that drives both the exit and the corresponding innovations is required.

The PESTLE analysis in this paper presents a Germany-specific case that cannot be directly transferred to other countries. Nevertheless, this case study offers an approach to situating peatland rewetting within a country-specific phase-out context and relating it to other well-known, politically navigated transition processes. This can strengthen the dimension of peatland rewetting in the public debate as an emission reduction measure.

#### Rewetting pathways: Importance of the rewetting pace and timing

It has to be taken into consideration that the paper assumes a linear CO<sub>2</sub> decrease within the rewetting pathways and has not considered the fact that there may be phases in which planning must first get underway and others in which many areas are rewetted, for example.

Further, the pathways assume a full rewetting of all drained peatlands under agricultural use, which is significantly higher than the 80 % assumed in the scenarios by Grethe et al. (2021) for Germany or Agora Agriculture (2024) on a European level. Since the paper aims to present scenarios and pathways in line with the Paris Agreement rather than a feasibility study, on this basis, the paper applies the pathway of Tanneberger et al. (2021).

The developed pathways and the presented area- and emission-gap underline once more the importance of the rewetting pace and timing (cf., Günther et al., 2020).

Politically justified budget: Financial dimension compared to the coal phase-out

The costs of rewetting agriculturally used peatlands are difficult to quantify precisely due to insufficient data, region-specific conditions and a large number of case-dependent cost factors (see Chapter 1, Section 1.2.2). The justified budget is initially independent of these uncertainties, as it describes a politically justified financial framework and not the actual costs incurred.

The politically determined financing of the coal phase-out is interpreted as the political willingness to pay (pWTP) to reduce emissions in a socially acceptable and just way. Based on this, a comparable, politically justified budget for the reduction of emissions through rewetting is derived.

Even if the coal phase-out path is adjusted over time, the initially signalled political willingness to pay for the socially acceptable emission reduction of the coal phase-out remains, which in turn was transferred to peatland rewetting in Paper 2.

While the coal phase-out provides guidance for the scope of the drainage phase-out budget, it does not provide guidance for its instruments and budget allocation or packages. The financial packages must be designed specifically for rewetting and require a high level of complexity in policy regulations as well. Financial resources could be used to promote (a) planning processes and technical implementation of rewetting, (b) business adaptation processes (c) investment and research in paludiculture, (d) development of value chains, utilization, refinement and (e) structural changes within the regions, but also authorities and administration. Furthermore (f), one complex and financially demanding issue might be the land exchange or compensation payments for farms, who have to ‘give up’ their land for the rewetting and (g) also, education and training (affected stakeholders, touching industries as well as the public) are components of a socially acceptable transition.

Wichmann et al. (2022) also transmit the coal phase-out to peatland rewetting in Germany and calculate that taxpayers finance the coal phase-out with 69 €/t to 93 €/t of avoided CO<sub>2</sub>, which indicates a political willingness to pay for climate protection. If this is transferred to the reduction of GHG emissions from peatlands, 180-243 million € could be made available annually by 2038 to avoid 2.6 million t of CO<sub>2e</sub> per year. The calculation of Paper 2 comes to a significantly higher justified budget since the basic unit here is the cumulative amount of tons of CO<sub>2</sub> mitigated along the pathway.

In Schäfer et al. (2022), an overall financing requirement (from 2022 to 2050) for conversion to paludiculture of 21.2 billion € was calculated. This budget is higher than the politically justified budget in paper 2. In order to be able to compare these two budget figures precisely, in a next step, it would be helpful to take a closer look at the individual financing elements used. Overall, however, it should be noted that the scenario of Schäfer et al. (2022) is a scenario for the establishment and implementation of paludiculture, of which about 60 % account for the climate protection bonus and 24 % for the costs of conversion to paludiculture and the politically justified budget describes a willingness to pay for the socially acceptable phasing out of drainage-based agriculture on peatlands. It should therefore also be taken into account that the budget of Schäfer et al. (2022) also includes funding to establish the innovation. Nordbeck and Hogl, (2024) mention the important role of the state as the main investor in peatland strategies, but also the crucial role of mobilising private funds to achieve rewetting goals.

#### Comparison with coal phase-out as a tool for science communication

The comparison between the coal phase-out and the rewetting of peatlands offers an approach to science communication, as it can illustrate the importance of this paradigm shift to a broad public. It is not only used in scientific discussions but is also recognised in public communication. Media reports are picking up on it (Spektrum, 2023; NDR, 2023; Deutschlandfunk, 2022). The comparison can serve as a bridge between climate policy and science on the one hand, and the perspectives and challenges of affected farmers on the other. It is already being employed by rewetting experts (Röder et al., 2024; Joosten, 2024; Tanneberger, 2023; Wichmann et al., 2022), as well as by farmers themselves, who use it as a frame of reference to convey the scale of the challenges they face (Landvolk Niedersachsen, 2024; NDR, 2023; Deutschlandfunk, 2022). This demonstrates that the comparison is supported from both a scientific standpoint and by those who are directly affected. It enables addressing the more ambitious rewetting pathways recommended by scientists, while acknowledging the historic efforts of farmers to reclaim the land and their contributions to agriculture, as well as the economic cost of rewetting.

However, if the coal phase-out is used as a blueprint for change in other sectors, it is essential not only to transfer its successes but also to learn from its weaknesses and failures.

#### Formation of a peatland commission

The Commission on Growth, Structural Change and Employment (KWSB) - also known as the 'Coal Commission' - was commissioned by the German government to develop a socially acceptable exit path from coal-fired power generation. Its task was to develop a mix of measures

and instruments that would support political decision-makers in the legislative process and enable a successful structural change. The 31 members of the commission were made up of representatives from business, politics, environmental organisations, affected regions and trade unions to create a social consensus.

After six months of work, the commission presented its final report in January 2019, which was submitted to the German government as a finalised coal compromise (Commission “Growth, Structural Change and Employment” – BMWK, 2019). This served as the basis and legitimisation for the following legislation on the coal phase-out and the strengthening of structures.

The Coal Commission was seen as a model for democratically legitimised decision-making processes, as it involved various stakeholders and contributed to state legitimacy through collaborative decision-making and implementation (Radtke and Löw Beer, 2024).

The German government used the commission's results to legitimise legislation on the coal phase-out and to strengthen existing structures (Radtke and Löw Beer, 2024).

As a learning from the Coal Commission, it is emphasised that a successful commission requires clear mandates and that the German government must communicate transparently how the recommendations will be used (Heilmann and Popp, 2020). Agora Energiewende (2019) cites a consensus-oriented political culture, a clear mandate without direct influence from the federal government and a high willingness to reach agreement as key conditions for success. Nevertheless, it became apparent in practice that the implementation of the recommendations by the German government deviated in part from the Commission's proposals, which led to frustration and criticism and undermined confidence in the effectiveness of the Commission (Heyen et al., 2020; Reitzenstein and Popp, 2019). There is fundamental criticism that the Coal Commission lacked a clear target for the phase-out path to be in line with the Paris Agreement, which led to frustration, particularly because the agreed coal phase-out is considered to be too slow in terms of emissions reduction.

From these shortcomings, it could be deduced that a peatland commission would require a clear target based on the legally binding emission reduction targets from which the rewetting pathway could be derived. It can also be concluded that it would counteract frustration if it were specified from the outset how binding the recommendations drawn up are for political implementation.

The work of the Coal Commission has attracted international attention because Germany, as it was the second-largest coal-producing country in the EU, has initiated a pioneering transition process. A peatland commission would be relevant in Germany, as the rewetting of peatlands under agricultural use has far-reaching economic and social consequences. Similar to how the

Coal Commission has developed a ‘Just Transition Pathway’ for the coal phase-out, a peatland commission could develop a just transition for agriculture on drained peatlands. It could involve experts, stakeholders and citizens in a structured dialogue to develop consensus-based strategies for the transition of drained agricultural land and ensure that economic alternatives, support structures, socially acceptable mitigation and a necessary pathway in line with climate targets are taken into account. The scientific review of the German coal phase-out (e.g. Radtke and Beer, 2024; Gürtler et al. 2021; Heilmann and Popp, 2020; Heyen et al., 2020; Agora Energiewende, 2019; Reitzenstein and Popp, 2019) offer valuable insights into the design of a possible ‘Peatland Drainage Phase-Out’ and the potential convening of a ‘Peatland Commission’ and provide a conclusion on what lessons could be learned from the coal commission, since successful and problematic aspects of the coal commission can be identified from existing reports. However, an international perspective can also be beneficial in developing the process, as there are also participatory approaches to developing a peatland strategy in other European countries (cf., Nordbeck and Hogl, 2024).

#### Reflections on the method

From a methodological perspective, it should be noted that PESTLE is more of an analytical framework than a methodological approach. With the help of PESTLE, however, the paper can organise the literature according to a number of predefined dimensions.

It is important to recognise that the chosen discount rate has a significant effect on the volume of the politically justified budget, which could be shown by applying three different discount rates. The paper assumes that the stakeholders negotiated the budget for the coal phase-out based on the present values (PV). Therefore, the pWTP to mitigate a cumulative tone is derived from the CO<sub>2</sub> emission mitigation along the pathway as PV and then in a second step, distributed to the rewetting pathways. A limitation lies in the assumption made within the paper that the budget was negotiated with PV in consideration.

As described in Tanneberger et al. (2021), the paper assumes a complete avoidance of CO<sub>2</sub> emissions. This assumption is based on the IPCC Wetlands Supplement (IPCC, 2014) and Tiemeyer et al. (2020), which assume a carbon sink at optimal water tables. However, as in some cases, rewetting could not restore the carbon sink function (Bianchi et al., 2021; Renou-Wilson, et al., 2016), the paper conservatively excluded CO<sub>2</sub> sequestration from the calculations.

It should be emphasised again that the paper focuses on CO<sub>2</sub> and not all greenhouse gases, as the carbon budget approach is considered suitable for assessing whether the targets and progress

of emission-reducing policies are compatible with the Paris Agreement (IPCC, 2021a SRU, 2020).

Considering the transferability of the pathways to other countries, it is important to note that the CO<sub>2</sub> emission factors before and after rewetting could differ due to variations in nutrient status and climate zones (IPCC, 2014). Additionally, emission factors can vary based on climate, soil, and hydrological conditions, even within a single country. However, it is important to emphasise that regardless of the exact CO<sub>2</sub> emission factor, timing and ambition of rewetting are of importance.

The approach to define a pWTP and derive a politically justified budget is, on the one hand, a very theoretical approach, but could, on the other hand, help to put considerations of financial packages into proportion to each other. Pointing out the pWTP of another profound transition pathway could set into relation the scheduled budget for peatland rewetting with reference to the mitigation of cumulative tons of CO<sub>2</sub>.

### **2.3 Paper 3: How Well are Peatlands Understood? Lessons from Measuring Subjective and Objective Knowledge**

#### *2.3.1 Key Findings*

Paper 3 shows a discrepancy between subjective and objective knowledge of peatlands and rewetting. Individuals with low objective knowledge tend to overestimate their knowledge, while those with high objective knowledge underestimate it - a pattern consistent with the Dunning-Kruger effect. It is particularly striking that those who overestimate their knowledge are less willing to accept new information (negative correlation with AOT).

Beyond that, differences in the correlation between determinants and the two types of knowledge can be shown. Education, income, time preference, connection to rural areas and the personal importance of environmental protection correlate more strongly with subjective knowledge than with objective knowledge. In contrast, trust in science shows a stronger positive correlation with objective knowledge than with subjective knowledge. While objective knowledge correlates negatively with risk preference, this determinant is most strongly positively associated with subjective knowledge. It is noticeable that participants whose families have contributed to the drainage of peatlands tend to overestimate their knowledge, while their objective knowledge is negatively correlated. A similar pattern can be seen among people with a right-leaning political view: They report a positive correlation with subjective knowledge, while they are also positively correlated with overestimating their knowledge.

These findings have implications for environmental communication. Communication strategies to increase objective knowledge should target groups with excessive self-confidence in their knowledge in order to counteract misinformation and resistance to climate protection measures, like the rewetting of peatlands. At the same time, targeted knowledge transfer can be useful for groups with high objective but low subjective knowledge to strengthen their confidence in their abilities and promote more active participation in the environmental debate.

### *2.3.2 Critical discussion*

#### Knowledge of society beyond the affected stakeholders

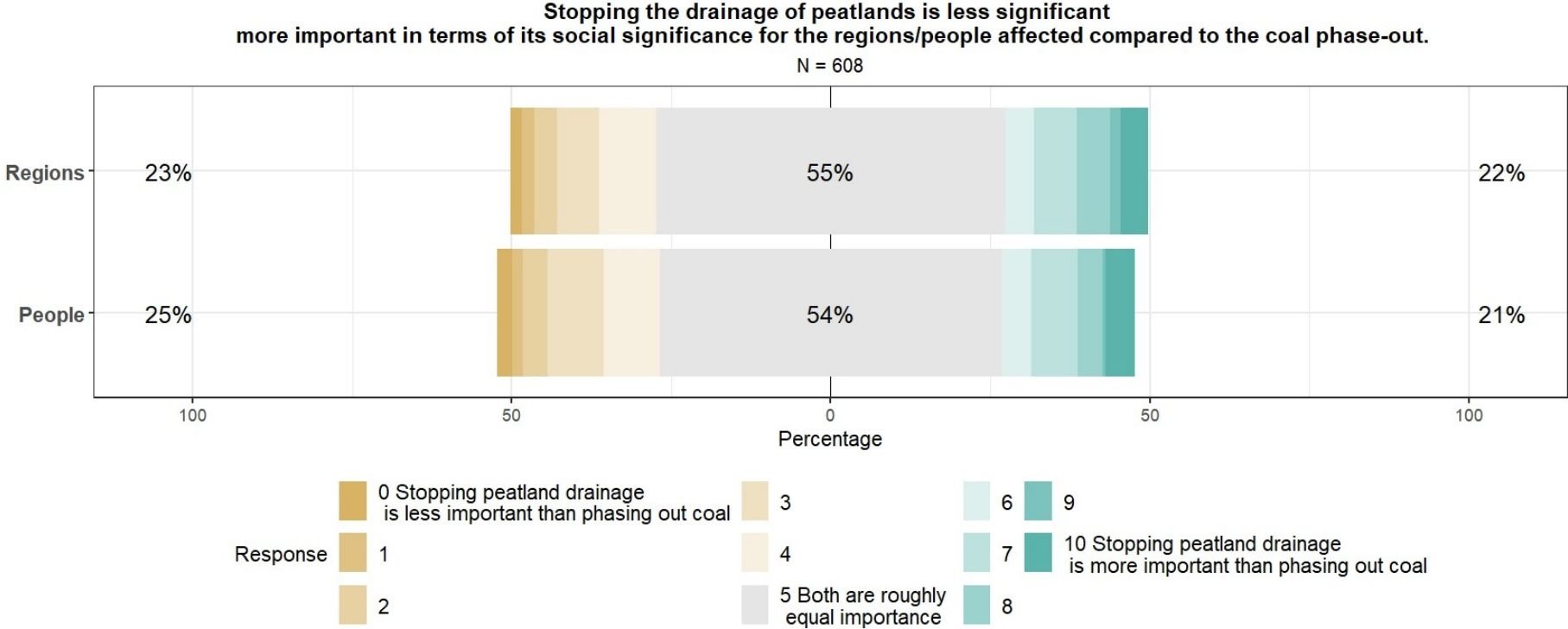
As demonstrated in Paper 1 and Paper 2, a broader societal perspective is essential for large-scale peatland rewetting, as it represents a task for society as a whole. Expanding knowledge assessments beyond directly affected groups adds valuable insights to the discourse by enabling a more comprehensive understanding of the public's knowledge of peatland rewetting. This, in turn, can inform targeted communication strategies, support public acceptance of policy measures, and provision of public funds.

Understanding public knowledge is not exclusive but rather complementary to the research of stakeholders' concerns and the way of making decisions. It contributes to a more holistic understanding of the societal dynamics surrounding peatland rewetting.

Since Paper 2 outlines a politically justified budget for rewetting based on the coal phase-out that would be financed through public funds, gaining public support becomes an important consideration.

As supplementary questions that go beyond the content of Paper 3, we also ask within the survey for the participants' assessment of the comparison between the coal phase-out and peatland drainage phase-out.

**Figure 1: Assessment of the comparison between the coal phase-out and peatland drainage phase-out**



Source: Own Presentation. For further information about the data, see the appendix (A1, A2, A3).

The descriptive analysis shows, that more than 70 % of the participants assess that stopping peatland rewetting is roughly equal to or even more important than phasing out coal for the people and the region. These results could provide initial indications about the public's understanding of the impacts of a peatland drainage phase-out for the affected people and regions, which could lead to an acceptance of budget funds.

#### The distinction between objective and subjective knowledge

In the practical design of surveys, it can also be a question of resources as to which type of knowledge is asked. If subjective and objective knowledge are the same, it would be more efficient to collect subjective knowledge with a single question than with 10 questions on factual knowledge.

Paper 3 indicates significant differences in the determinants of these two knowledge types, highlighting the risk of misrepresenting knowledge gaps by relying solely on subjective self-assessments, leading to ineffective outreach. Other studies also confirm, that accurately measuring knowledge is crucial for understanding its role in policy support and fostering informed debates (Bergquist et al., 2022; Light et al., 2022; Li and Zhao, 2019; Drews and van den Bergh, 2016; Shi, 2016). Khatibi (2021) highlights a strong connection between public knowledge and environmental engagement, emphasising the importance of distinguishing between objective and subjective knowledge. Studies show that while objective knowledge often correlates positively with support for climate policies, subjective knowledge does not necessarily exhibit the same link (Drews and van den Bergh, 2016).

By refining knowledge assessment methods and targeting communication efforts towards groups with objectively lower knowledge - such as younger individuals or those with low actively open-minded thinking (AOT) - policy interventions can be made more effective. Additionally, addressing discrepancies between subjective and objective knowledge can help mitigate misinformation and enhance public understanding of peatland rewetting.

#### Knowledge and political support

Public acceptance is crucial for implementing policies in democratic societies (cf., Khatibi et al., 2021). A lack of support can hinder policy adoption, reduce compliance, and weaken climate action effectiveness (Lipari et al., 2024; Bergquist et al., 2022). Research shows that public knowledge influences environmental concern and climate policy support (Khatibi et al., 2021; Shi et al., 2016). Knowledge not only fosters policy acceptance but also enables citizens to make informed decisions (Shi, 2016).

There is an ongoing scientific debate about the role of knowledge in shaping support for policy measures (Bergquist et al., 2022; Light et al., 2022; Drews and van den Bergh, 2016; Shi et al.,

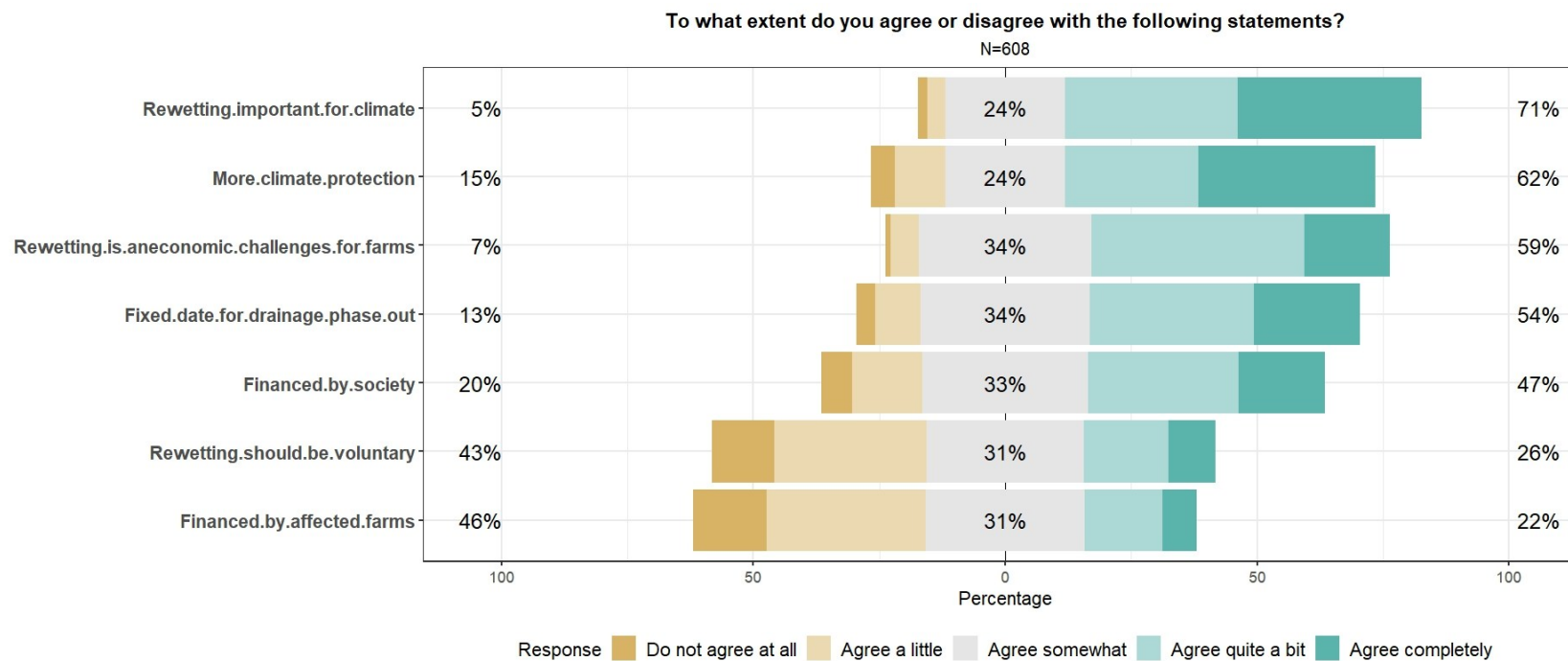
2016; Stoutenborough and Vedlitz, 2014). The paper contributes to this debate by systematically measuring knowledge about peatlands for the first time, providing topic-specific insight into the relationship between knowledge and determinants. However, other factors beyond knowledge, such as political ideology and economic concerns, also shape policy support (Lipari et al., 2024; Stoutenborough and Vedlitz, 2014).

Additional factors such as emotions, social norms, political narratives, and socio-economic concerns likely play a role in explaining public support for peatland rewetting policies. Therefore, further research is needed to explore these interdependencies and to better understand the complex mechanisms that shape policy attitudes.

Khatibi et al. (2021) highlight the strong interrelation between public knowledge, awareness, and engagement in the context of climate change. They argue that well-targeted communication strategies are essential, as improved knowledge and awareness can foster greater engagement with climate policy. This engagement, in turn, has the potential to enhance both policy design and implementation. Moreover, the authors emphasise that active public involvement is not only a result of increased knowledge but can also positively influence individual attitudes and behaviours. This connection forms a link between knowledge and the formation of rewetting as a just transition, which also means the engagement of affected and local communities.

#### Agreement for various statements on rewetting

To provide further insight into the attitudes of the participants in our survey, here is some additional material. Figure 2 shows the approval ratings for various statements on the rewetting of peatlands.

**Figure 2: Approval ratings for various statements on the rewetting of peatlands**

**Source:** Own Presentation. For further information about the data, see the appendix (A1, A2, A3).

**Note:** The original statements are as follows: "Rewetting peatlands is important for climate protection", "More should be done politically for climate protection", "Rewetting peatlands places economic challenges on farms", "There should be a fixed date by which all rewettable peatlands are rewetted", "Financial burden should be shouldered by society", "Rewetting of peatlands for agriculture should be voluntary", "Financial burden should be shouldered by affected farms"

71 % of respondents consider peatland restoration to be an important contribution to climate protection, which emphasises the broad support for peatland protection measures as part of climate policy. Over half of the respondents recognise the economic challenges for farmers: 59 % agree that rewetting represents a high financial burden for farms. This is also reflected in the opinions on financing. While 47 % believe that society should bear the costs, only a minority of 22 % are in favour of affected farmers financing rewetting themselves.

In terms of implementation, 54 % are in favour of setting a binding end date for complete rewetting, while only 26 % are in favour of purely voluntary implementation. This indicates that many people expect clear political guidelines, but with socially equitable funding. The results also show that many people recognise the importance of peatlands, but also the burden of rewetting for the farmers affected. These findings provide insights into the general population and can help to develop communication strategies or to support the implementation of policy measures.

#### Overconfidence as a risk for political acceptance

With the Dunning-Kruger effect, Paper 3 provides empirical evidence for an overestimation of knowledge within the topic of peatland and peatland rewetting. Stoutenborough and Vedlitz (2014) summarise that individuals who overestimate their knowledge of climate change are unlikely to perceive greater risk or to change their willingness to act, as overconfidence often reduces openness to new information. As public support for policy action is often necessary, this resistance to learning can hinder efforts to close the knowledge gap between scientists and the public, ultimately making it more difficult to achieve broad political support for climate action. Previous studies also highlight a connection between belief in pseudoscience, advocacy by non-experts in policymaking, and the Dunning-Kruger effect (Arroyo-Barrigüete et al., 2023; Motta et al., 2018).

Paper 3 represents the first investigation of this effect in the context of peatlands and peatland rewetting and can therefore be considered a vital contribution to this emerging field of research. One limitation of the study, however, is that it does not establish a direct link between the observed effect and wider political acceptance. Future research and empirical studies could usefully build on these results to further investigate this important relationship. Further research could also design questionnaires to ask about the accuracy of confidence (cf., Fischer et al., 2019) or the risk perception concrete on climate change (cf., Stoutenborough and Vedlitz, 2014) or the negative impacts of peatland drainage to deepen the understanding of the Dunning-Kruger effect. Also, the knowledge and confidence among experts, journalists, politicians and laypersons could be interesting to follow (cf., Sundbland et al., 2009).

Excessive confidence in one's own knowledge has been linked to ideological rigidity, increased voter turnout, and stronger partisan identification (Ortoleva and Snowberg, 2015). Moreover, research suggests that those who reject scientific consensus most strongly tend to be particularly overconfident in their knowledge (Light et al., 2022; Fernbach et al., 2019; Motta et al., 2018). These findings indicate that overconfidence may pose a challenge to gaining public support for peatland rewetting policies, underscoring the need for targeted communication strategies.

#### Implications for communication strategies

Arroyo-Barrigüete et al. (2023) and Motta et al. (2018) investigate the correlation between the Dunning-Kruger effect and belief in pseudo-scientific theories. They show a positive correlation and summarise that this effect should not be underestimated, but that further research is needed into how the Dunning-Kruger effect can be reduced.

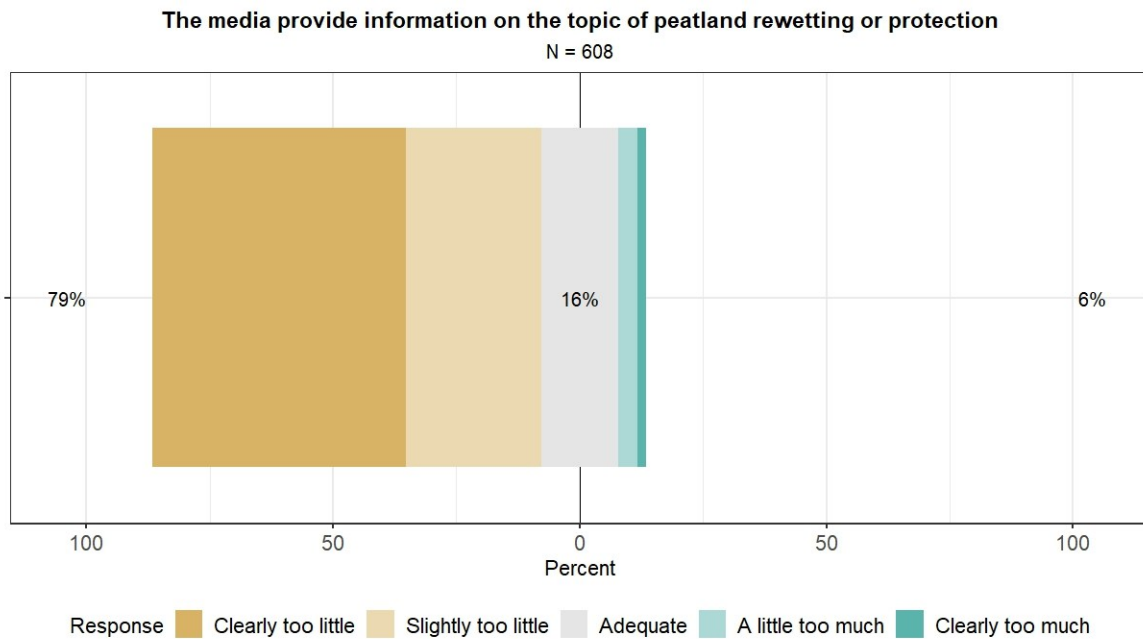
Schreiber et al. (2023) suggest, for example, that people should also be made aware of the Dunning-Kruger effect in order to make people who overestimate themselves more receptive to information again.

In addition, effective communication strategies by government and authorities should go beyond merely disseminating knowledge; they must also foster self-reflection on what individuals know and do not know. This highlights the need for targeted communication strategies that address both overconfidence and underconfidence. Communication efforts should therefore be tailored to different knowledge profiles, ensuring that those with factual knowledge are encouraged to contribute to discourse while those with inflated confidence are provided with nuanced information that prompts reconsideration.

However, the understanding of how knowledge is distributed across different socioeconomic and demographic groups is limited. Kuhn et al. (2024) investigated the public perception of ecosystem restoration for carbon dioxide removal by comparing peatlands, forests and seagrass meadows in Germany and found that peatlands evoked negative associations.

Linking further supplemental questions (from the survey related to the dataset in Paper 3) addressing the issue of communication strategies, the participants showed that the majority (79 %) think that media information about rewetting is too little (Figure 3). This indicates that the topic is perceived as underrepresented in public reporting. This, in turn, could point to an information demand and an openness for more information on peatlands and rewetting.

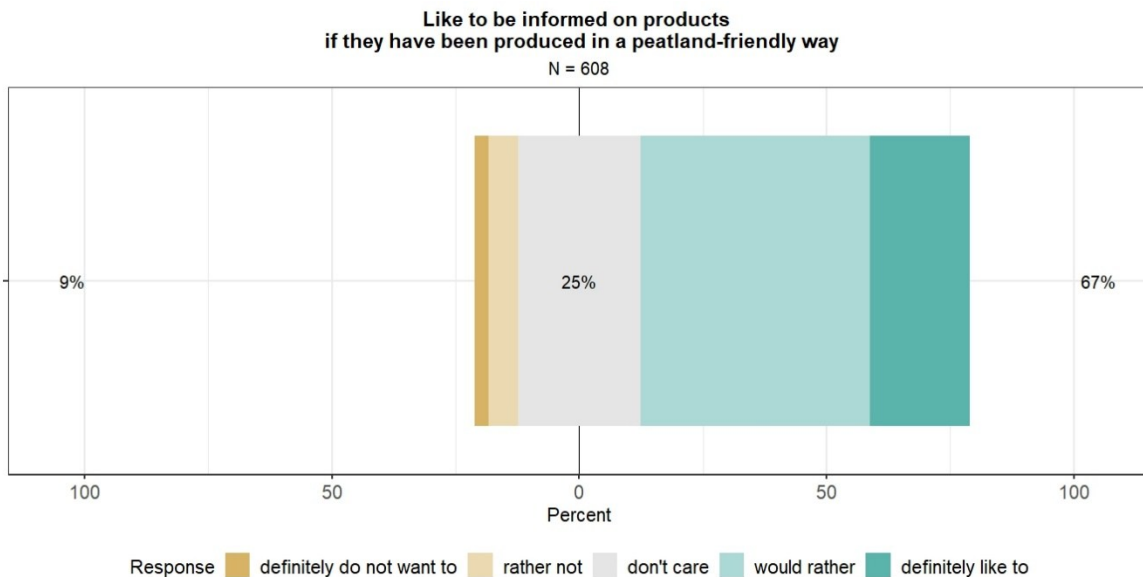
**Figure 3: Assessment of media information about rewetting**



**Source:** Own Presentation. For further information about the data, see the appendix (A1, A2, A3).

Figure 4 shows that 67 % of respondents would rather or definitely like to receive information on products if they have been produced in a peatland-friendly way, while only 9 % do not want such information. This also indicated a general openness to peatland information on products.

**Figure 4: Information about peatland on products**



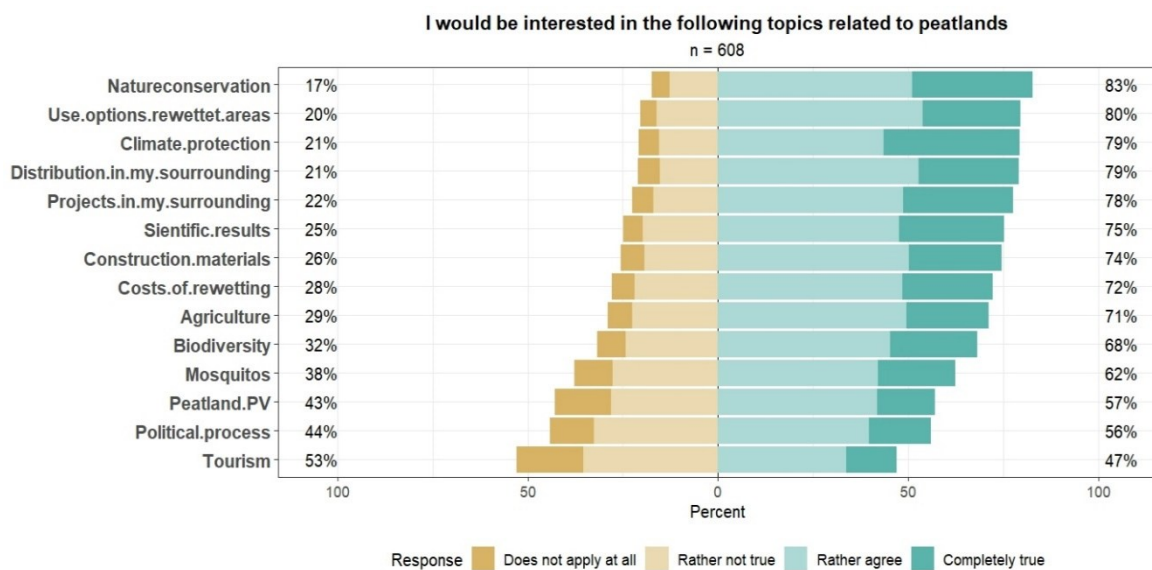
**Source:** Own Presentation. For further information about the data, see the appendix (A1, A2, A3).

Figure 3 and Figure 4 point to a communication gap: there is a lack of both general reporting on rewetting and targeted consumer information on peatland-friendly products. In terms of a communication strategy, the results suggest that both the media and companies could play a

greater role in providing information. Schäfer et al. (2022) analysed labels on products using criteria from scientific policy consulting and showed that labels (as information on the products) were classified as difficult to implement and the direct contribution achieving climate targets are very low, but it was also mentioned that the effect of labels on consumers should not be underestimated (WBAE and WBW, 2016).

The following Figure 5 shows the information interest of participants in various topics relating to peatlands. It supplements the previous findings on the openness for information on rewetting and the perception of media coverage.

**Figure 5: Interest in topics in relation to peatlands**



**Source:** Own Presentation. For further information about the data, see the appendix (A1, A2, A3).

The results complement the high level of interest in more information about peatlands and openness to information on products. A strong interest is shown in nature conservation and climate protection (83 % and 79 % in favour, respectively). Many respondents are also interested in the potential utilisation of rewetted areas (80 %) and local peatland projects (78 %). In addition to ecological issues, economic aspects are also important: 72 % are interested in the costs of rewetting and 71% in agricultural utilisation options. This indicates that not only the protection but also the economic viability of peatlands plays a role. Political processes (56 %) and photovoltaics on rewetted areas (57 %) seem to be less central for the public, while potential disadvantages such as mosquitoes (62 %) attract attention. With 47 %, the lowest interest is in information about tourism but there is a high level of interest in peatland projects and distribution in the surroundings of the participants. The broad support for nature and climate-related topics indicates that targeted communication on these aspects would meet with great interest. The high level of interest in utilisation options and economic aspects shows that

it is not just about nature conservation, but also about practicable solutions for land use and financing.

Considering these results, campaigns could focus on practical aspects such as utilisation options, local projects, scientific findings and climate and nature conservation, since these topics generate the most interest.

#### Reflection on the method

As part of this study, a quiz was designed to systematically measure objective knowledge about peatlands and peatland rewetting. The quiz covers three key knowledge categories: General Knowledge, Use and Distribution, Emissions and Political Processes, and Wet Use and Paludiculture. By developing quiz-style questions, this study represents the first structured attempt to assess objective peatland knowledge on a national scale. However, it is essential to acknowledge that the formulation of questions can influence the measured objective knowledge.

The quiz was designed to cover a wide range of knowledge, and to minimise the impact of guessing, participants were only awarded a point if they selected the correct answer without marking incorrect options. In Paper 3, the total score out of 10 questions was analysed, providing insights into overall knowledge levels. Future research could conduct a more detailed examination of individual knowledge categories, particularly regarding wetland use and innovations, where participants exhibited the lowest knowledge scores.

The survey was conducted nationwide in Germany without specific weighting for rural areas or peatland-rich regions. This approach assumed that funding for peatland rewetting is a societal responsibility, requiring informed citizens even in regions not directly affected. The analysis provides information about the correlations but not about causal relationships, which is important for the interpretation of the results.

### **3. Contribution of the dissertation**

#### **3.1 Theoretical contribution**

A theoretical contribution lies in the integration of transition research and peatland rewetting governance, bridging two research areas and opening a broad field for further studies.

1. Paper 1 expands the innovation-focused discourse (e.g. paludiculture, peatland-PV) by the importance of actively phasing out unsustainable technology and practices (e.g. peatland drainage for agriculture). This approach allows existing policy measures to be embedded within a broader theoretical framework, providing them with additional conceptual

grounding and opens up new concepts and approaches for peatland rewetting governance research. Beyond that, Paper 1 represents a valuable case study for transition research.

2. Building on this foundation, Paper 1 and Paper 2 jointly highlight the rewetting of agriculturally used drained peatlands as a socio-technical transition, which emphasises that peatland rewetting is not just a technical challenge but also a socially embedded process requiring active governance.
3. Paper 2 further develops this argument by establishing a link between the coal phase-out and peatland rewetting.
4. Paper 3 contributes to this theoretical foundation by introducing a cognitive dimension to peatland governance. It is the first study integrating the Dunning-Kruger effect into peatland rewetting research, shedding light on the role of public knowledge.

### **3.2 Applied contribution**

By contextualising peatland rewetting as a politically decided and designed transition process, the dissertation offers concrete governance, financial, and communication strategies that can guide policymakers, stakeholders, and researchers.

1. Paper 1 emphasises peatland drainage phase-out as an actively governed process rather than a market-driven transition. This is crucial for policymakers, as it emphasises the need, e.g. for a defined pathway, integrated policy instruments, stakeholder engagement and aftercare strategies, restructuring of structures and processes and knowledge sharing.
2. Paper 2 emphasises the multidimensional nature of peatland rewetting by highlighting the impacts on the agricultural sector, but also on the socio-cultural and historical dimensions.
3. Paper 2 contributes by establishing a conceptual and financial link between coal phase-out and peatland rewetting. By calculating an emission- and area gap between the current rate of rewetting and that required by the Paris Agreement, the paper underlines the importance of rewetting timing and ambition. The paper introduces the politically justified budget, an approach that translates the preferences into peatland rewetting pathways based on a political willingness to pay for a socially acceptable emission reduction pathway, as demonstrated in the coal phase-out. This framework offers practical applications for policymakers by quantifying the dimension of a financial framework if the same preferences as for the coal phase-out were applied for a socially acceptable pathway.
4. By analysing public knowledge of peatland rewetting to get points of reference for communication strategies, Paper 3 contributes to science communication and communication strategies, e.g. government and authorities. The paper identifies possible

target groups (e.g. individuals over- or underestimating their knowledge; individuals with low knowledge levels) and the underlying determinants.

5. The supplementary material in Section 2.3.2 provides an initial insight into the agreement on various statements regarding rewetting, openness to information on rewetting, and the perception of media coverage.

### **3.3 Methodical contribution**

1. Paper 1 characterises peatland rewetting as a socio-technical transition. To the best of my knowledge, this paper is the first to spell out an exnovation governance approach on peatland rewetting.
2. Paper 1 uses existing literature to develop a four-dimensional framework (discourse, policy instruments, agency, and justice) to structure recommendations from science for governance interventions and policy strategies. In a second step, this framework is applied to analyse the existing political strategies (the National Peatland Protection Strategy and the Federal-Länder Agreement) to evaluate how current rewetting policy efforts align with an exnovation governance approach.
3. Paper 2 applies the PESTLE framework to analyse rewetting as a socio-technical regime change. This offers a structured assessment of political, economic, social, technological, legal, and environmental factors. It is the first scientific paper explicitly deals with the comparison between coal phase-out and peatland rewetting and thus places it in a scientific context.
4. Additionally, Paper 2 presents an area- and emission gap analysis for three different rewetting pathways in comparison to the current rewetting rates.
5. Furthermore, Paper 2 introduces a politically justified budget (pWTP) by using exploratory calculations to transfer the political willingness to pay for the coal phase-out into a financial framework for a socially acceptable rewetting of drained peatlands under agricultural use. This methodological approach could also be applied to compare other transitions aimed at reducing emissions in a just and socially acceptable way.
6. Paper 3 makes a methodological contribution by designing a nationwide survey to assess public knowledge of peatlands and peatland rewetting. The study developed a quiz-based knowledge assessment divided into three thematic categories to measure objective knowledge.
7. Paper 3 addresses the methodological challenge of distinguishing between subjective and objective knowledge. Using an exploratory approach, it provides an overview of the

determinants that influence knowledge, over- and underconfidence, and serves to identify patterns within the data.

8. Paper 3 contributes to the existing literature by providing the first nationwide survey of both objective and subjective knowledge relating to peatland and peatland rewetting. The developed quiz is also an addition to the existing literature and could be further developed and used in other peatland surveys. Additionally, the dissertation sheds light on the respondents' interest in various peatland-related topics on which campaigns could be built.

#### **4. Implications for policy and practice**

1. *Structured governance approach for terminating the drainage* (Paper 1): In order to create a transition to the rewetting of agricultural peatlands in line with climate targets, a governance approach should not only support innovation, but also regulate the phase-out of drainage. The exnovation governance approach offers an opportunity to organise this phase-out in a holistic and socially just manner.
2. *Address all four dimensions of the exnovation governance for a pertinent policy mix* (Paper 1): The analysis of the German rewetting strategy shows the following aspects are still outstanding in terms of exnovation governance: (a) integrate and synchronize peatland rewetting into broader climate, agriculture and land-use policies (b) defined termination of peatland drainage, (c) detach from the paradigm of voluntarism, (d) create a participatory process or a commission, (e) design a roadmap for the justice dimension to build towards a just transition, (f) restructure and extend processes and capacities in administration, (g) apply control policies (h) adjust the CAP and the CAP strategy plan, (i) provide extensive financial resources.
3. *A legally binding phase-out timeline for peatland drainage* (Paper 1 and Paper 2): Similar to the coal phase-out, this would create planning security for landowners, farmers and neighbouring industries and signal a long-term political commitment. A complementary mix of regulatory measures and financial support mechanisms would help to organise the transition and adaptation in a just manner and increase acceptance.
4. *Extensive financial funds for a just and socially acceptable peatland drainage phase-out* (Paper 2 and Paper 1):  
A socially and just peatland drainage phase-out will require extensive financial funds. What German politics is willing to pay to make such a pathway of reducing emissions socially acceptable was signalled by the financial packages for the coal phase-out. If this political willingness to pay is transferred, a significantly higher financial budget than is currently

envisaged would be justified for a peatland rewetting pathway in line with the Paris Agreement.

5. *Learning from the coal phase-out* (Paper 2): Lessons can be learnt from the shortcomings and successes of the coal phase-out process when designing a rewetting pathway. Initiatives such as the establishment of a commission could be transferred to develop a socially acceptable rewetting pathway in dialogue with stakeholders. Many aspects of the coal phase-out have also been analysed in the literature, and lessons could be transferred to these analyses for the peatland phase-out.
6. *Development of a targeted communication strategy* (Paper 3): Effective communication strategies (addressing different knowledge levels as well as over- and underestimation) to improve knowledge are a component in fostering acceptance of peatland rewetting and related policies. Based on the supplemental descriptive analysis in the discussion, it can be shown that there is an openness for more information, and both the media and companies could play a greater role in providing information. With regard to the topics of interest among survey participants, it can be concluded that campaigns could focus on practical aspects such as utilisation options, local projects, scientific findings, and climate and nature conservation, as these generate the most interest.

## **5. Limitation of the Dissertation:**

Specific limitations are already discussed within the papers (Chapters 2, 3 and 4) and the paper-wise discussion (Section 2). Within this section, I want to highlight six overall limitations.

1. The concept of just transition is increasingly being discussed in the context of peatland rewetting (Kaljonen et al., 2024; Lonkila et al., 2024; Lempinen and Vainio, 2023; Laasasenaho et al., 2022; Banerjee et al., 2022). In this dissertation, just transition is understood with a focus on jobs, labour markets, and affected communities (Paper 2), as well as a conceptual approach within socio-technical transitions (Paper 1).

Wang and Lo (2021) and Heyen et al. (2020) provide an overview of the various ways in which just transition can be defined and conceptually applied, demonstrating that the term encompasses a much broader spectrum than its traditional focus on employment and economic restructuring.

A holistic examination of peatland rewetting through the lens of just transition would require an in-depth analysis of justice dimensions, distributional effects, and governance mechanisms (cf., Abram et al., 2022), which extends beyond the scope of this dissertation and which, however, presents a valuable avenue for future research.

2. It should be noted that the exnovation governance approach itself is still in its early stages and that research and discourse within transition research are still in progress (Paper 1).
3. While this dissertation demonstrates the relevance of the exnovation framework, it does not fully explore its interaction with innovation processes, such as paludiculture, peatland-PV, carbon markets, mobilising of private capital and alternative management strategies (Paper 1).
4. The dissertation focuses on Germany and its agricultural peatlands, which may limit the applicability of concrete results to other countries, but the approaches of the concepts are still transferable (Paper 1 to 3). In this context, it should be recognised that governance structures, land use policies, narratives and societal attitudes towards rewetting vary from country to country and may also differ across different land uses (e.g. forestry, peat extraction for energy and horticulture).
5. The calculated politically justified budget for peatland rewetting, derived from the German coal phase-out, provides a useful political benchmark but does not represent the volume of the actual costs of rewetting. The budget does not account for region-specific cost factors, such as hydrological conditions, land-use conflicts, or economic opportunity costs. Further empirical research is needed to refine cost assessments and explore the feasibility of financing mechanisms tailored to regional conditions (Paper 2).
6. The survey of public knowledge identifies the determinants that drive subjective and objective knowledge. But it should be noted that knowledge is not the only driver of policy acceptance, and there is still a debate about the impact of knowledge on the perception and acceptance of political measures. Not considered factors such as emotions, political ideology, economic interests and trust in institutions also influence public attitudes towards peatland rewetting. This should be addressed and investigated in further research (Paper 3).

## 6. Further Research

The following points outline potential starting points for future research arising from the limitations discussed in Section 5 and beyond.

1. *Peatland Rewetting as just transition in a whole-system approach*: A holistic examination of peatland rewetting through the lens of just transition would provide an in-depth analysis of its justice dimensions, distributional effects, and governance mechanisms. This approach could take up the themes identified from the literature by Wang and Lo (2021) in which the just transition concept is discussed, such as a labour-oriented concept, a theory of socio-

technical transition, a governance strategy, an integrated framework for justice; and public perception (linked to Limitation 1. – Section 5).

2. *International comparisons of peatland rewetting governance*: This dissertation focuses on Germany, but peatland-rich countries such as the Netherlands, Finland, the UK, Ireland, and Indonesia have implemented different rewetting policies. Some of them try to establish instruments that mobilise private capital, and others have anchored a clear top-down pathway. Comparative studies could help to identify best practices, assess the role of different governance structures, and explore how socio-economic and political contexts influence transition outcomes.
3. *Peatland rewetting transition in other sectors*: This dissertation focuses on the impacts due to the rewetting of agriculturally used peatlands. Even though this is the major land use category of drained peatlands in Germany, other sectors are also affected due to rewetting efforts in line with the Paris Agreement in Germany and internationally. How these sectors could transition in a socially acceptable way is important to look at to comprehensively assess the overall impacts of a rewetting peatland transition. Specially to look at the sectors forestry, energy, and horticulture (in interlinkage with peat extraction) would advance science and governance perspective nationally and internationally (linked to Limitation 4. – Section 5).
4. *Research on economic effects and financial demands*: Further economic research is required to refine cost estimates and develop targeted financing mechanisms for a just transition. While in Paper 2, a politically justified budget for the rewetting of peatlands is derived, future studies should examine the regional differences in implementation costs, the opportunity costs for landowners, and potential revenue sources from paludiculture or carbon markets. However, studies on the impacts on labour forces are also lacking. With meaningful studies on these parameters, the justified budget could then be put into relation with statements on financial needs, as the assessment of the long-term economic impacts on rural economies and employment will be crucial for designing effective compensation measures (linked to Limitation 5 in Section 5 and beyond).
5. *Innovation–Exnovation nexus in peatland rewetting transition*: The Innovation–Exnovation nexus linked to peatland rewetting in line with climate targets requires further research. While this dissertation primarily focuses on the phase-out of peatland drainage, sustainable land-use innovations such as paludiculture, rewetting-compatible grazing systems, and peatland-PV play a crucial role in decreasing opportunity costs and making the transition more economically viable. Future research should point out how policy frameworks can

simultaneously promote exnovation and sustainable innovations (linked to Limitation 3 in Section 5).

6. *Longitudinal studies on public knowledge and policy acceptance:* Further empirical studies on knowledge and political acceptance in the general population are of significance since they would provide deeper insights into the social dimension of peatland rewetting. Paper 3 highlights knowledge gaps and cognitive biases, but further research is needed for a deeper understanding of the role of knowledge. Other factors like emotions, personal experiences and attitude to certain topics, how public attitudes evolve, how resistance to rewetting policies can be addressed, and how trust in science and governance can be strengthened are of research interest. Examining the effectiveness of different communication strategies in fostering public acceptance could help to improve science communication and stakeholder engagement (linked to Limitation 6 in Section 5).
7. *Effectiveness of awareness campaigns on peatland protection and peatland-friendly land use:* Given the identified gap in media coverage and identified interest areas in peatland-related topics, future studies could evaluate the impact of targeted awareness campaigns. Research could assess whether increased information availability influences public perception, policy support, and consumer behaviour regarding peatland-friendly products.
8. *Public willingness to support peatland rewetting:* Since many respondents are interested in the costs of rewetting and the implications for stakeholders, further research could explore the public's willingness to pay for peatland restoration through taxes, donations, or the purchase of peatland-friendly products. Comparative studies across different socioeconomic groups or regions could offer deeper insights.
9. *Multi-level governance and EU policy integration:* It also needs to be explored how peatland rewetting incentives are affected by national, regional, and EU-level policies. Future research should investigate how EU climate, environment and biodiversity policies, the CAP, and carbon farming initiatives can be aligned with national rewetting strategies to maximise policy coherence and financial support.

By addressing these research gaps, future studies can contribute to a more comprehensive understanding of the process of peatland rewetting and support the development of evidence-based policies that integrate climate change mitigation and socio-economic resilience in the context of a socially responsible and just transition.

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## 8. Appendices

### A1: Variables and measurement of supplemental material

**Table A1.1: Variables and measurement of supplemental material**

| Label                                                                                                                   | Question/Statement                                                                                                                               | Range of Scale | Values (incl. comments)                                                                                                                                                                                     |
|-------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Region                                                                                                                  | "In my opinion, the stop of peatland drainage is of less / greater societal importance for the affected regions compared to the coal phase-out." | 0-10           | 0 = The stop of peatland drainage is less important than the coal phase-out<br>5= Both are about equally important<br>10 = The cessation of peatland drainage is more important than the coal phase-out     |
| People                                                                                                                  | In my opinion, the stop of peatland drainage is of less / greater societal importance for the affected people compared to the coal phase-out.    | 0-10           | 0= The cessation of peatland drainage is less important than the coal phase-out<br>5= Both are about equally important<br>10 = The cessation of peatland drainage is more important than the coal phase-out |
| The financing of large-scale rewetting of peatlands should be borne by the affected agricultural businesses themselves. | To what extent do you agree or disagree with the following statements?                                                                           | 1-5            | 1=Strongly disagree;<br>2=Disagree;<br>3=Somewhat agree;<br>4=Agree;<br>5= Strongly agree;                                                                                                                  |
| The rewetting of peatlands is important for climate protection.                                                         | To what extent do you agree or disagree with the following statements?                                                                           | 1-5            | 1=Strongly disagree;<br>2=Disagree;<br>3=Somewhat agree;<br>4=Agree;<br>5= Strongly agree;                                                                                                                  |
| Rewetting of agriculturally used peatlands should only take place on a voluntary basis.                                 | To what extent do you agree or disagree with the following statements?                                                                           | 1-5            | 1=Strongly disagree;<br>2=Disagree;<br>3=Somewhat agree;<br>4=Agree;<br>5= Strongly agree;                                                                                                                  |
| Rewetting of peat soils places high economic demands on agricultural businesses.                                        | To what extent do you agree or disagree with the following statements?                                                                           | 1-5            | 1= Strongly disagree;<br>2=Disagree;<br>3=Somewhat agree;<br>4=Agree;<br>5= Strongly agree;                                                                                                                 |
| The financing of large-scale rewetting of peatlands should be borne by society as a whole.                              | To what extent do you agree or disagree with the following statements?                                                                           | 1-5            | 1= Strongly disagree;<br>2=Disagree;<br>3=Somewhat agree;<br>4=Agree;<br>5= Strongly agree;                                                                                                                 |
| A fixed point in time should be set in the near future by which                                                         | To what extent do you agree or disagree with the following statements?                                                                           | 1-5            | 1= Strongly disagree;<br>2=Disagree;<br>3=Somewhat agree;                                                                                                                                                   |

|                                                           |                                                                                                  |     |                                                                                                                 |
|-----------------------------------------------------------|--------------------------------------------------------------------------------------------------|-----|-----------------------------------------------------------------------------------------------------------------|
| all rewettable areas must be rewetted.                    |                                                                                                  |     | 4=Agree;<br>5= Strongly agree;                                                                                  |
| Media Inform about rewetting                              | The media provide information on the topic of peatland rewetting or peatland protection:         | 1-5 | 1= Clearly too little;<br>2=Slightly too little;<br>3=Adequate;<br>4=A little too much;<br>5= Clearly too much; |
| Information on Products                                   | “Would you like to be informed on products if they were produced in a peatland-friendly manner?” | 1-5 | 1= Definitely do not want to;<br>2=Rather not;<br>3=Do not care;<br>4=Would rather;<br>5= Definitely like;      |
| Tourism                                                   | “The following topics related to peatlands would interest me”                                    | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies                    |
| Use and spread of peat soils in my local area             | “The following topics related to peatlands would interest me”                                    | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies                    |
| Construction materials from plants grown on rewetted land | “The following topics related to peatlands would interest me”                                    | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies                    |
| Costs of rewetting                                        | “The following topics related to peatlands would interest me”                                    | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies                    |
| Climate protection                                        | “The following topics related to peatlands would interest me”                                    | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies                    |
| Photovoltaic systems on rewetted areas                    | “The following topics related to peatlands would interest me”                                    | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies                    |
| Agriculture                                               | “The following topics related to peatlands would interest me”                                    | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies                    |
| Mosquito issues                                           | “The following topics related to peatlands would interest me”                                    | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies                    |
| Biodiversity                                              | “The following topics related to peatlands would interest me”                                    | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies                    |

CHAPTER 5

|                                  |                                                               |     |                                                                                              |
|----------------------------------|---------------------------------------------------------------|-----|----------------------------------------------------------------------------------------------|
| Scientific findings              | “The following topics related to peatlands would interest me” | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies |
| Rewetting projects in my region  | “The following topics related to peatlands would interest me” | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies |
| Nature conservation in peatlands | “The following topics related to peatlands would interest me” | 1-4 | 1=Does not apply at all;<br>2=Rather does not apply;<br>3=Rather applies;<br>4=Fully applies |

**Source:** Own Presentation

**A2: Description of the supplemental material**

The supplemental material in section 2.3.2 is based on the survey described in Chapter 4. Therefore, all information about the survey and the related dataset and r packages can be found in Chapter 4: Section 2, A2, A4.



## **Abstract**

This cumulative dissertation analyses the rewetting of agriculturally used peatlands in Germany as a socially acceptable and climate-target-compliant transition. From the perspectives of governance, economics and public knowledge, the work identifies points of reference for political design and governance.

The first paper recognises peatland drainage as a former innovative practice that is harmful to the climate and must be actively terminated. The term ‘exnovation’ is used to describe how governance can disrupt entrenched patterns, with e.g., binding phase-out targets, legal requirements, support programmes, public discourse and compensation payments. This governance approach aims to ensure a fair transition and the sustainable reconfiguration of agricultural practices on peatlands.

The second article compares peatland rewetting with Germany’s coal phase-out across political, economic, social, ecological and legal dimensions. The coal phase-out represents a governed process that aimed to reduce emissions in a socially acceptable way. This comparison deepens the understanding of the multidimensional impacts of rewetting and underscores its character as a socio-technical transition. The calculation of a “politically justified budget” between 13.8 billion - 16 billion € indicates the funding level - relative to the coal phase-out - justified for a socially acceptable rewetting in line with climate targets.

Paper 3 is based on a survey, which collected objective and subjective knowledge of the general population in Germany about peatlands and rewetting. The study shows that people with little knowledge tend to overestimate their knowledge. The dissertation considers knowledge as an important aspect for informed decision-making and the acceptance of political measures.

The dissertation highlights that rewetting is a task for society as a whole, involving a profound, multidimensional transition. For this change to be socially acceptable and in line with climate targets, the end of drainage should be actively shaped politically and requires binding phase-out targets, sufficient funding and targeted communication.



## **Zusammenfassung**

Diese kumulative Dissertation analysiert die Wiedervernässung landwirtschaftlich genutzter Moorflächen in Deutschland als einen sozial verträglichen und klimazielenkonformen Wandel. Aus den Perspektiven von Governance, Ökonomie und öffentlichem Wissen identifiziert die Arbeit Anknüpfungspunkte für die politische Gestaltung und Steuerung.

Der erste Artikel charakterisiert die Moorentwässerung als eine ehemals innovative Praxis, die jedoch klimaschädlich ist und aktiv beendet werden muss. Der Begriff „Exnovation“ beschreibt, wie Governance eingefahrene Muster und Strukturen durch z.B. verbindliche Ausstiegsziele, gesetzliche Vorgaben, Förderprogramme, einen öffentlichen Diskurs sowie Ausgleichszahlungen durchbrechen können. Dieser Governance-Ansatz zielt darauf ab, einen sozial verträglichen Übergang und die nachhaltige Neuausrichtung landwirtschaftlicher Praktiken auf Moorböden zu ermöglichen.

Der zweite Artikel vergleicht die Wiedervernässung von landwirtschaftlich genutzten Mooren mit dem Kohleausstieg in Deutschland entlang politischer, wirtschaftlicher, gesellschaftlicher, ökologischer und rechtlicher Dimensionen. Der Kohleausstieg stellt einen politisch gesteuerten Prozess dar, der auf eine sozialverträgliche Reduktion von Emissionen abzielte. Dieser Vergleich vertieft das Verständnis für die multidimensionalen Auswirkungen der Wiedervernässung und unterstreicht deren Charakter als sozio-technischen Wandel. Die Berechnung eines „politisch gerechtfertigten Budgets“ von 13,8 bis 16 Milliarden Euro zeigt auf, in welcher Größenordnung – in Relation zum Kohleausstieg – eine klimazielenkonforme und sozialverträgliche Wiedervernässung finanziell gerechtfertigt wäre.

Der dritte Artikel basiert auf einer Umfrage, die objektives und subjektives Wissen der deutschen Allgemeinbevölkerung über Moore und Wiedervernässung erhoben hat. Die Untersuchung zeigt unter anderem, dass Menschen mit wenig Wissen dazu tendieren, ihr Wissen zu überschätzen. Die Dissertation versteht Wissen als einen zentralen Faktor für informierte Entscheidungen und die Akzeptanz politischer Maßnahmen.

Die Arbeit macht deutlich, dass die Wiedervernässung eine gesamtgesellschaftliche Aufgabe ist, die einen tiefgreifenden, multidimensionalen Wandel bedeutet. Damit dieser Wandel gesellschaftlich akzeptiert wird und den Klimazielen entspricht, muss das Ende der Entwässerung politisch aktiv gestaltet werden – durch verbindliche Ausstiegsziele, ausreichende finanzielle Mittel und gezielte Kommunikation.



## **Danksagung**

Ein herzlicher Dank an all die Menschen, die mich in den letzten Jahren begleitet und in unterschiedlichster Art und Weise zum Gelingen dieses Promotionsvorhabens beigetragen haben.

Ein besonders großer Dank an die Co-Autor:innen der drei Paper, denn ohne euch würde es das Herzstück dieser Promotion nicht geben: Leonard Frank, Sven Grüner, Sebastian Lakner, Anke Nordt, Franziska Tanneberger, Johannes Wegmann und Sabine Wichmann.

Bei meinem Doktorvater Sebastian Lakner möchte ich mich insbesondere für die Betreuung, das Vertrauen und den wissenschaftlichen Freiraum bedanken. Auch möchte ich die Hilfe von Sven Grüner hervorheben, du warst eine riesen Unterstützung bei dem dritten Paper.

Meine Kolleginnen und Kollegen in Rostock haben meiner Arbeit ein Zuhause gegeben und mich in der Zeit sehr unterstützt. Dabei möchte ich mich insbesondere bei Marie Meyer-Jürshof bedanken, die eine Weggefährtin und irgendwie auch Leidensgenossin vom ersten bis zum letzten Tag war: und nun haben wir es beide geschafft!

Bei allen Reviewern der Papiere, den Gutachter:innen dieser Arbeit sowie dem Publikum bei Vorträgen auf Konferenzen möchte ich mich für die Fachexpertise und konstruktiven Anmerkungen bedanken.

Außerdem ein herzlicher Dank an die Personen, die den Entwurf dieser Arbeit gelesen und mir sehr wertvolle Hinweise gegeben haben.

Ein Dank geht auch an Christine Chemnitz als Mentorin über das Mentoring-Programm für Doktorandinnen der Universität Rostock.

Johannes Weißmann, du hast mich die gesamte Zeit begleitet, danke für die Möglichkeit des Abschaltens aber auch des fachlichen Austausches und die schöne Zeit mit dir.

Auch möchte ich all den tollen Leuten in Greifswald danken, mit denen ich zusammenwohne oder Zeit verbringe: Egal ob fachlicher Input, ein Bierchen am Hafen oder eine ganze Baustelle stemmen, alles ist möglich.

Insbesondere möchte ich hier meinen Großeltern danken: Wir haben in den letzten Jahren den Dialog zwischen den Generationen in Bezug auf die Wiedervernässung verstärkt geführt. Das ist eine große Bereicherung für mich.

Und natürlich ein riesen Dank an meine Eltern Heike Sommer und Martin Kulinna, Oma Maria, Onkel Wolfgang, meinen Schwestern Liv und Fee und dem ganzen Rest der Bande.



## **Eidesstattliche Erklärung**

Hiermit erkläre ich durch eigenhändige Unterschrift, die vorliegende Dissertation selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet zu haben. Die aus den Quellen direkt oder indirekt übernommenen Gedanken sind als solche kenntlich gemacht. Die Dissertation ist in dieser Form noch keiner anderen Prüfungsbehörde vorgelegt worden.

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Ort, Datum

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Unterschrift der Doktorandin



## Authorship contribution

| Paper                                                                                                                                                                                                                                                                                           | Individual contribution of Pia Sommer in % | Authorship contribution statement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Peatland rewetting as drainage exnovation – A transition governance perspective</p> <p>Published in <i>Land Use Policy</i> 143 (2024) 107191<br/> <a href="https://doi.org/10.1016/j.landusepol.2024.107191">https://doi.org/10.1016/j.landusepol.2024.107191</a></p>                        | 65%                                        | <p><b>Pia Sommer:</b> Writing – review &amp; editing, Writing – original draft, Project administration, Investigation, Conceptualization. <b>Leonard Frank:</b> Conceptualization, Investigation, Writing – original draft, Writing – review &amp; editing.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <p>Deriving a justified budget for peatland rewetting – Applying the German coal phase-out as a blueprint</p> <p>Published in <i>Land Use Policy</i> 147 (2024) 107363<br/> <a href="https://doi.org/10.1016/j.landusepol.2024.107363">https://doi.org/10.1016/j.landusepol.2024.107363</a></p> | 65%                                        | <p><b>Pia Sommer:</b> Writing – review &amp; editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. <b>Sebastian Lakner:</b> Writing – review &amp; editing, Writing – original draft, Supervision. <b>Anke Nordt:</b> Writing – review &amp; editing, Writing – original draft. <b>Franziska Tanneberger:</b> Writing – review &amp; editing, Writing – original draft. <b>Johannes Wegmann:</b> Writing – review &amp; editing, Visualization, Methodology.</p>                                                                                                                                                                                                                                                                                                                                                  |
| <p>How Well are Peatlands Understood? Lessons from Measuring Subjective and Objective Knowledge</p> <p>Submitted</p>                                                                                                                                                                            | 65%                                        | <p><b>Pia Sommer:</b> Conceptualization, Methodology, Design of the Questionnaire, Validation, Formal Analysis, Investigation, Data Curation, Writing Original Draft, Writing- Review &amp; Editing, Visualization, Project Administration, Approval of the final version of the manuscript. <b>Sven Grüner:</b> Conceptualization, Methodology, Design of the Questionnaire, Validation, Investigation, Writing Original Draft, Writing- Review &amp; Editing, Approval of the final version of the manuscript. <b>Sabine Wichmann:</b> Writing Original Draft, Writing – Review &amp; Editing, Expert Input and Discussion of the Questionnaire, Approval of the final version of the manuscript. <b>Sebastian Lakner:</b> Writing Original Draft, Writing – Review &amp; Editing, Supervision, Discussion of the Questionnaire, Approval of the final version of the manuscript</p> |

## **Curriculum Vitae**

### **Beruflicher Werdegang**

Nicht für die online Publikation vorgesehen.

## **Beruflicher Werdegang**

Nicht für die online Publikation vorgesehen.

Greifswald, den 05. Februar 2026

## List of Publications

- Schreiner, Vera, Marion Mehring, Janina Kleemann, Jennifer Hauck, Stefan Knauß, Christian Poßer, Christian Schleyer, [...], **Pia Sommer**, Thilo Wellmann, Peter Keil, Heidi Wittmer 2025. 'Towards Transformative Change for Biodiversity: What Can We Learn from Case Studies in Germany?' *Journal of Environmental Management* 386: 125663. doi:10.1016/j.jenvman.2025.125663.
- Sommer, Pia** and Frank, Leonard (2024): 'Peatland Rewetting as Drainage Exnovation – A Transition Governance Perspective'. *Land Use Policy* 143: 107191. doi:10.1016/j.landusepol.2024.107191.
- Sommer, Pia**; Sebastian Lakner, Anke Nordt, Franziska Tanneberger, and Johannes Wegmann (2024): 'Deriving a Justified Budget for Peatland Rewetting – Applying the German Coal Phase-out as a Blueprint'. *Land Use Policy* 147: 107363. doi:10.1016/j.landusepol.2024.107363.
- Lakner, Sebastian, Sven Gruner, **Pia Sommer**, Ute Hasenöhr, Zachary Turk, Hannah Bohner, Bernd Klauer, Menko Koch, Marie Meyer-Jurshof, Anne-Christine Mupepele, Andre Mascarenhas, Alexandra-Maria Klein, Carola Paul, Florian Jansen, Marion Mehring, Franziska Tanneberger, Helmut Winkler, Pe'er Guy, Hubertus Paetow (2024): Indirekte Treiber der Biodiversitätsentwicklung. Faktencheck Artenvielfalt. Bestandsaufnahme und Perspektiven für den Erhalt der biologischen Vielfalt in Deutschland. München: oekom verlag, 1049–1119. DOI: 10.14512/9783987263361
- Wiegmann, Kirsten; Scheffler, Margarethe; Schneider, Christian; Lakner, Sebastian; **Sommer, Pia**; Meyer-Jürshof, Marie (2023): Klimaschutz in der GAP 2023-2027. Wirkungsbeitrag und Ausgaben 2. Auflage (Texte), 2023 (103/2022).
- Hirschelmann, Sophie; Peters, Jan; **Sommer, Pia** (2023): Moorschutz in Deutschland: Warum die Bundesregierung jetzt handeln muss. In: Der Mooratlas 2023; Heinrich-Böll-Stiftung.
- Sommer, Pia**; Lakner, Sebastian; Nordt, Anke; Tanneberger, Franziska; Wegmann, Johannes (2022): Der Kohleausstieg als Politisches Modell für die Moorwiedervernässung? Eine Aufstellung der Gemeinsamkeiten und Unterschiede. Konferenzbeitrag auf der GEWISOLA. 62. Jahrestagung. 07.- 09.09.2022 in Hohenheim.
- Sommer, Pia** (2022): Kohleausstieg als Blaupause. In: Moore – Trümpfe in der Klimakrise, Politische Ökologie (Nr. 169). S. 93-96. ISSN: 2625-543X.
- Scheffler, Margarethe; Wiegmann, Kirsten; Lakner, Sebastian; **Sommer, Pia**; Meyer-Jürshof, Marie (2022): Wieviel Klimaschutz steckt in der 1. Säule der GAP? – Analyse und politische Empfehlungen. Fact Sheet. 29 Seiten. Umweltbundesamt (UBA).
- Lakner, Sebastian; Jurasinski, Gerald; **Sommer, Pia** (2021): Klima und Landwirtschaft – Auswirkungen und Politikoptionen für eine nachhaltige Transformation für mehr Klimaschutz. Bundeszentrale für politische Bildung (bpb).

## Conference Contributions

**Sommer, Pia** (2024): Peatlands and drainage exnovation: A transition governance perspective. IFZO Annual Conference 9 – 10 October 2024 “Fragmented Transformations in the Baltic Sea Region: The Role of Innovations and Pioneers of Change”, October 9 and 10, 2024 in Greifswald, Germany.

**Sommer, Pia**; Lakner, Sebastian; Nordt, Anke; Tanneberger, Franziska; Wegmann, Johannes: (2023): A politically justified budget for the 1.5°C compatible rewetting of peatlands in Germany. EAAE in Rennes XVII EAAE Congress Rennes; 29 August to 1 September 2023; Session: Socio-economics of Climate-friendly Peatland Use.

**Sommer, Pia** and Frank, Leonard (2023): „Understanding peatland rewetting as exnovation“ at 51th Annual conference of the Swiss Society for Agricultural Economics and Agricultural Sociology; April 20 and 21, 2023; in AgroVet Strickhof of the ETH Zürich, Eschikon, Lindau (ZH).

**Sommer, Pia**; Lakner, Sebastian; Nordt, Anke; Tanneberger, Franziska; Wegmann, Johannes (2022): „Der Kohleausstieg als politisches Modell für die Moorwiedervernässung? Eine Aufstellung der Gemeinsamkeiten und Unterschiede“ at 62. Jahrestagung der GEWISOLA 2022 in Hohenheim.

**Sommer, Pia** and Lakner, Sebastian (2021): „Der Kohleausstieg als Model zur Förderung der Wiedervernässung von Mooren“ at 31. Jahrestagung der Österreichischen Gesellschaft für Agrarökonomie - Strategies for the agricultural and food sector and rural areas in times of multiple crises; 16.-17. September 2021 (online). Tagungsband: [https://oega.boku.ac.at/fileadmin/user\\_upload/Tagung/2021/OEGA-TAGUNGSBAND\\_2021.pdf](https://oega.boku.ac.at/fileadmin/user_upload/Tagung/2021/OEGA-TAGUNGSBAND_2021.pdf)

**Sommer, Pia** and Lakner, Sebastian (2021): „Der Kohleausstieg als Model zur Förderung der Wiedervernässung von Mooren“ at VÖW – Sommerakademie: Nachhaltige Landnutzung – zwischen wirtschaftlichen Rahmenbedingungen, agrarpolitischen Vorgaben und gesellschaftlichen Ansprüchen (15.-18. September 2021) auf Gut Siggen.