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Emotions related to climate change and their links to climate action
- behavioural and neuroimaging studies

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1. Abstract

Climate change evokes a wide range of emotions, yet the mechanisms linking them to pro-environmental behaviour (PEB) remain insufficiently understood. The aim of this dissertation was to examine climate emotions as appraisal-based processes and to test how they relate to pro-environmental behaviour at experiential, behavioural, and brain levels. Climate emotions were examined from the perspective of the Component Process Model and their behavioural and brain correlates were investigated in a unique multi-method research programme combining qualitative study, stimulus development and validation, behavioural experiments, and functional neuroimaging. First, interviews with people concerned about climate change showed that climate emotions are complex, context-dependent, and constructed through appraisals of relevance, causality, implications, coping potential, and normative significance. These findings were used to develop and validate the Emotional Climate Change Stories (ECCS), a standardised stimulus dataset designed to elicit distinct climate emotions. Then, ECCS were used in large-scale behavioural experiments in two independent samples to test whether induced climate emotions increase pro-environmental behaviour. Although inductions of anger, hope, and compassion were effective at the self-report level, a post-manipulation increase in PEB was not observed. Finally, a functional magnetic resonance imaging study showed that climate anger and hope recruited brain regions consistent with appraisal-based processing, including areas related to relevance, social meaning, self-referential evaluation, and future-oriented thought. Climate-relevant decisions engaged a number of regions related to valuation and cognitive control processes. Yet, consistent with the behavioural experiments, brief elicitation of climate anger and climate hope did not increase PEB. Participants exposed to stories designed to evoke climate anger, climate hope, or sustain a neutral emotional state did not show statistically significant differences in brain activity while making climate-relevant decisions. In contrast, participants' baseline climate anger, reported before the experimental manipulation, was positively associated with PEB. This pattern suggests that climate action was more closely related to pre-existing climate anger than to emotions briefly induced before the decision. Taken together, these findings suggest that climate emotions matter for action not merely when they are briefly triggered, but when they become a part of persons' habits, values and identity.

2. Streszczenie

Zmiana klimatu wywołuje szerokie spektrum emocji, jednak mechanizmy łączące je z zachowaniami prośrodowiskowymi są nadal niewystarczająco poznane. Celem rozprawy było zbadanie emocji klimatycznych jako procesów opartych na ocenach poznawczych oraz sprawdzenie, jak wiążą się one z zachowaniami prośrodowiskowymi na poziomie doświadczenia, zachowania i aktywności mózgu. Emocje klimatyczne były badane z perspektywy Modelu Procesów Składowych (*Component Process Model*) a ich behawioralne i mózgowo-korelaty zostały przeanalizowane w ramach unikalnego programu badawczego obejmującego badanie jakościowe, opracowanie i walidację bazy bodźców, eksperymenty behawioralne oraz funkcjonalne obrazowanie mózgu.

Wywiady z osobami zaniepokojonymi zmianą klimatu wykazały, że emocje klimatyczne są złożone, zależne od kontekstu i konstruowane poprzez oceny poznawcze dotyczące istotności, przyczynowości, konsekwencji, możliwości radzenia sobie oraz znaczenia normatywnego sytuacji. Wyniki te posłużyły do opracowania i walidacji wystandaryzowanej bazy bodźców emocjonalnych (*Emotional Climate Change Stories*) zaprojektowanych do wywoływania poszczególnych emocji klimatycznych. Następnie bodźce wykorzystano w eksperymentach behawioralnych w dwóch niezależnych próbach, aby sprawdzić, czy indukowane emocje klimatyczne zwiększają zachowania prośrodowiskowe. Chociaż wywołanie złości, nadziei i współczucia było skuteczne na poziomie samoopisu, po manipulacji eksperymentalnej nie zaobserwowano wzrostu zachowań prośrodowiskowych.

Badanie fMRI wykazało, że złość i nadzieja klimatyczna angażowały struktury mózgu zaangażowane w oczekiwane procesy poznawcze, w tym obszary związane z oceną istotności, znaczeniem społecznym, samoodniesieniem oraz myśleniem ukierunkowanym na przyszłość. Podejmowanie decyzji związanych z klimatem angażowało szereg struktur związanych z procesami wartościowania i kontroli poznawczej. Jednak, spójnie z wynikami wcześniejszych eksperymentów behawioralnych, krótkotrwałe wywołanie złości i nadziei klimatycznej nie zwiększyło zachowań prośrodowiskowych. Uczestnicy eksponowani na bodźce zaprojektowane w celu wywołania złości klimatycznej, nadziei klimatycznej lub utrzymania neutralnego stanu emocjonalnego nie różnili się istotnie

statystycznie pod względem aktywności mózgu podczas podejmowania decyzji związanych z klimatem. Natomiast wyjściowe nasilenie złości klimatycznej, deklarowane przed manipulacją eksperymentalną, było pozytywnie skorelowane z zachowaniami prośrodowiskowymi. Ten wzorzec wyników sugeruje, że działanie prośrodowiskowe było silniej związane z wcześniejszą złością klimatyczną niż z emocjami krótko wywołanymi bezpośrednio przed decyzją. Łącznie wyniki te wskazują, że emocje klimatyczne mają znaczenie dla działania niekoniecznie wtedy, gdy są chwilowo wzbudzone, lecz wtedy, gdy stają się częścią nawyków, wartości i tożsamości osoby.

3. Keywords

climate change, emotions, pro-environmental behaviour, decision-making, appraisal, functional magnetic resonance imaging

4. Abbreviations

ACC - Anterior cingulate cortex
BIDS - Brain Imaging Data Structure
BOLD - Blood-oxygen-level-dependent signal
CET - Carbon Emission Task
CPM - Component Process Model
DLPFC - Dorsolateral prefrontal cortex
DMN - Default mode network
DMPFC - Dorsomedial prefrontal cortex
ECCS - Emotional Climate Change Stories
FD - Framewise displacement
FDR - False discovery rate
fMRI - Functional magnetic resonance imaging
FWE - Family-wise error
GHG - Greenhouse gases
GLM - General linear model
ICE - Inventory of Climate Emotions
IPCC - Intergovernmental Panel on Climate Change
ITI - Inter-trial interval
MCC - Mid-cingulate cortex
MNI - Montreal Neurological Institute template space
OFC - Orbitofrontal cortex
PCC - Posterior cingulate cortex
PEB - Pro-environmental behaviour
RRES - Reading and Rating Emotional Stories
ROI - Region of interest
SIB - Self-interest behaviour
TPJ - Temporoparietal junction
TR - Repetition time
VMPFC - Ventromedial prefrontal cortex
WEPT - Work for Environmental Protection Task

Label	Meaning
ANG, ANX, COM, GUI, HOP, NEU	Story categories: anger, anxiety, compassion, guilt, hope, and neutral
TAR, CON	Target and control stories
ANGER, COMPASSION, HOPE, NEUTRAL	Experimental groups
anger, anxiety, compassion, guilt, hope	Rating scales, written in full in the text

5. General introduction

5.1. The climate crisis

Climate change is widely recognised as a significant threat to humans and many other species worldwide (IPCC, 2023). Recent studies across multiple countries indicate that people of all ages are increasingly aware of climate change and becoming more concerned about its impacts (Brosch, 2025; Goldberg et al., 2021; Marks et al., 2021; Morrison et al., 2018; Steentjes et al., 2017).

At the same time, the global response to the climate crisis is inadequate. To avoid catastrophic consequences, anthropogenic greenhouse gas (GHG) emissions must be drastically reduced and global warming limited to 1.5°C above pre-industrial levels (*Paris Agreement. United Nations Framework Convention on Climate Change*, 2015). Despite political, legal, and technological efforts, GHG emissions continued to rise in 2024 (Climate Action Tracker, 2024). With current policies in place, emissions in 2030 are projected to exceed safe levels by 20 to 27 billion tonnes of CO₂ equivalent, potentially leading to a global temperature rise of approximately 2.7°C by 2100, with a significant risk of surpassing 3°C of warming (Climate Action Tracker, 2024). While there is widespread agreement on the need for systemic solutions to address climate change (IPCC, 2018, 2021), changes in individual behaviours remain crucial. In high-income countries, consumption-based household footprint accounts for approximately 60% of total GHG emissions (Koide et al., 2021; Rau et al., 2022). The persistent habits of high individual consumption in wealthier, rapidly developing countries pose a major obstacle to effective climate change mitigation. Finding ways to motivate individuals to engage in behavioural change could help global efforts to limit and slow climate change.

Environmental psychology has made significant contributions to understanding why people protect the environment, identifying socio-demographic (e.g., age, income, education level), psychological (beliefs, norms, habits), and contextual (e.g., access to technology, economic incentives) predictors of pro-environmental behaviour (PEB) (Carrus et al., 2021; Graham-Rowe et al., 2015; López-Mosquera et al., 2015; van Valkengoed & Steg, 2019). Klöckner (2013) shows that research in this field was largely based on four dominant frameworks: the Theory of Planned Behaviour (Ajzen, 1991;

Yuriev et al., 2020), the Norm-Activation Theory (Onwezen et al., 2013; Schwartz, 1977), the Value-Belief-Norm Theory (Oreg & Katz-Gerro, 2006; Stern et al., 1999), theoretical models of habitual behaviour (Verplanken & Aarts, 1999), or models aiming at integrating the aforementioned frameworks, such as Comprehensive Action Determination Model (CADM, Klöckner & Blöbaum, 2010). Notably, these models paid relatively little attention to the role of emotions.

Recent meta-analytic evidence consistently identifies emotions as among the strongest psychological determinants of PEB, with effect sizes comparable to or exceeding those of mere attitudes and intentions (Carrus et al., 2021; van Valkengoed & Steg, 2019). Affect and emotions have also been found to be important predictors of other related outcomes that are not behavioural in nature, such as climate risk perception (van der Linden, 2015), willingness to engage in mitigation behaviours (Xie et al., 2019), or support for climate policies (Goldberg et al., 2021). However, much remains to be learned about the mechanisms by which emotions influence PEB. Most of the available evidence about the links between emotions and PEB comes from correlational studies or large-scale surveys. Relatively few experiments have established clear causal links between emotions and meaningful pro-environmental behaviour; most studies instead rely on self-reported intentions or token behaviours with little real climate impact (Dablander et al., 2025). Additionally, the substantial heterogeneity in the effect sizes (Carrus et al., 2021; Shipley & van Riper, 2022) suggests that, while the relationship exists, its strength varies across study designs and contexts. This variability, rather than undermining the importance of emotions, highlights the need to identify more specific mechanisms by which emotions influence climate-related decisions, such as the activation of certain cognitive appraisals or action tendencies (Brosch, 2021; Harth et al., 2013; Reser & Bradley, 2017). Besides this focus, researchers need clear definitions and operationalisations of emotions, validated and naturalistic stimuli, and solid, pre-registered experimental designs.

5.2. Defining climate emotions

Researchers began examining affective phenomena related to the climate crisis in the early 2000s (Pihkala, 2022). Key milestones in this field include the introduction of the concept of solastalgia - a place-related distress (Albrecht et al., 2007) - and other ‘psychoterratic

syndromes' (Albrecht, 2011), as well as the creation of the first classification systems for climate emotions (Böhm, 2003). During the 2010s, researchers grew especially interested in “eco-anxiety” (Robbins & Moore, 2013) and other discrete emotions, such as anger, guilt or sadness, particularly focusing on their impact on mental health and potential to motivate climate action. Over time, a debate emerged regarding normalizing versus pathologizing approaches to climate-change-related apprehension associated with significant distress and impairment in psychosocial functioning (Clayton, 2020). The 2020s are marked by efforts to organise these findings, as reflected in the creation of taxonomies (Landmann, 2021; Pihkala, 2022) and several meta-analyses on the relationship between climate emotions and PEB (Carrus et al., 2021; Schneider et al., 2021; Shipley & van Riper, 2022).

Several psychometric tools for measuring climate-related emotions were also developed, including the Climate Anxiety Scale (Clayton & Karazsia, 2020), the Eco-anxiety Scale (Hogg et al., 2021), and the Inventory of Climate Emotions (Marczak, Wierzba, et al., 2023). All these works highlighted the need for measures beyond self-report and a nuanced approach to defining emotion by its appraisal patterns. In this thesis, emotional responses to climate change are treated as intentional¹ and context-dependent experiences arising from the coordination of physiological, cognitive, and social processes (Barrett, 2012, 2017; 2007). Within this broader paradigm, the Component Process Model (CPM; proposed by Scherer, 2001, 2009; 2014 and further developed with Sander et al., 2005, 2018) - is adopted as the main theoretical framework (Fig. 1).

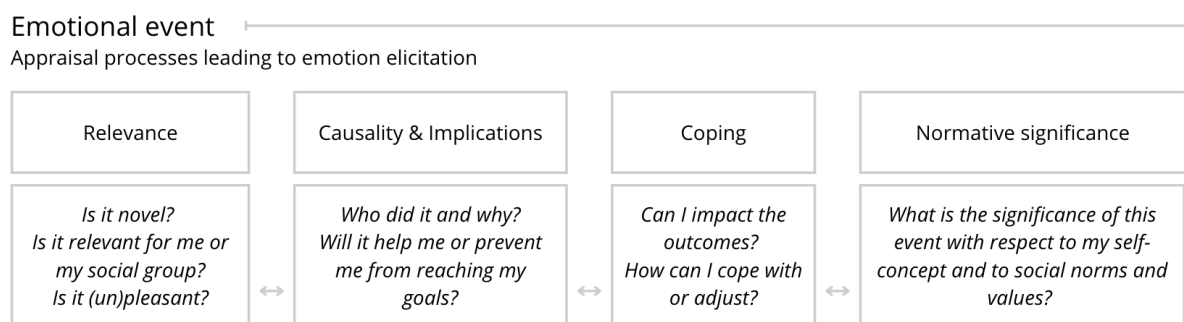


Figure 1. Emotion elicitation process in the Component Process Model. Adapted for this thesis from Scherer (2001, 2009, 2014), Sander (2015, 2018), the second appraisal stage is labelled *Causality and Implications* to distinguish evaluations of what caused an event from evaluations of its likely consequences.

¹ 'Intentional' is used here in the phenomenological sense, as *directed towards* or *about* something (Blackburn, 2005).

According to CPM, emotions are elicited by appraisals of events with respect to relevance, causality and implications, coping potential, and normative significance. The structure of appraisal stages in CPM has undergone conceptual refinements over time. Earlier formulations of the model proposed a hierarchical and sequential structure, with the second stage labelled 'implication assessment,' encompassing causality, goal-conduciveness, discrepancy, and urgency (Sander et al., 2005). In this thesis, the second appraisal stage is described as Causality and Implications to distinguish evaluations of what caused an event from evaluations of its likely consequences. This distinction is particularly relevant for climate emotions, where responsibility attribution and future-oriented consequences often co-occur but may rely on partly different cognitive and neural processes (Brevers et al., 2021; Brosch et al., 2018; Mohammadi et al., 2023; Schurz et al., 2021). Appraisals trigger a cascade of processes that together constitute an emotional episode: changes in autonomic arousal, action tendencies, motor expressions, and subjective feelings. These mechanisms are responsible for the functional aspect of emotions, through which emotions influence decision-making and guide behaviour. Appraisal theories are practical as integrative models in affective neuroscience (Brosch, 2021; Sander et al., 2018), and recent studies have demonstrated their applicability for deconstructing complex emotional constructs into tangible cognitive processes linked to brain activity (Campbell et al., 2023; Mohammadi et al., 2023).

A number of discrete climate emotions have been identified in the literature to date (Pihkala, 2022). In this thesis, the selection of emotion categories for experimental investigation was guided by both empirical findings and theoretical considerations. First, priority was given to emotions most consistently associated with climate action to focus on constructs likely to relate to the behavioural outcomes examined in the planned experiments. Previous research has associated several climate emotions with approach-oriented tendencies relevant to climate action (Brosch, 2021; Kovács et al., 2024; Reser & Bradley, 2017; Schneider et al., 2021; Shipley & van Riper, 2022; Stanley et al., 2021). Second, the selection was further constrained using the Component Process Model (CPM). Specifically, emotions whose appraisal profiles were theoretically expected to support action-oriented tendencies were selected for further investigation. Table 1 presents the decomposition of these climate emotions into their constituent CPM appraisals.

Table 1. Decomposition of selected climate emotions into constitutive CPM appraisals.

Emotion	Emotion object	Appraisals
Goals threatened by climate change: physical, social, and economic safety, health and well-being, procreation, identity, living in a just world, and good self-image		
Anger	Perpetrators of the climate crisis (e.g., polluters, policymakers).	Relevance: Climate change is threatening and obstructive to personal and collective goals. Causality & Implications: Harm and injustice caused by an identifiable agent; consequences are severe and affect the vulnerable. Coping: Restore justice through punishment. Normative significance: Perpetrators violate moral norms.
Anxiety	An urgent, real, and severe threat of climate disruption.	Relevance: Climate change directly threatens personal safety. Causality & Implications: The threat is systemic and diffuse; the consequences are uncertain but potentially severe. Coping: Self-preservation. Normative significance: Inaction is unacceptable.
Compassion	Innocent victims of climate change (e.g., elderly, children, animals).	Relevance: The suffering of others is morally significant and incongruent with affiliative goals. Causality & Implications: The victims perceived as innocent, harm is undeserved and avoidable. Coping: Moral responsibility to help exists despite personal costs. Normative significance: Alleviating suffering aligns with prosocial norms.
Guilt	One's own actions that contribute to climate change.	Relevance: One's own behaviour threatens environmental values. Causality & Implications: Self or in-group is responsible for contributing to harm; consequences are negative. Coping: Repair the harm. Normative significance: Actions are discrepant with one's moral self-image and environmental values.
Hope	A safe future that can be secured through collective efforts.	Relevance: One's own future depends on climate action. Causality & Implications: Positive outcomes are possible and contingent on collective agency. Coping: Cooperate and support solutions. Normative significance: Involvement in climate action is seen as morally positive behaviour.

A more detailed illustration - especially in terms of brain mechanisms related to appraisal patterns - is provided for climate anger and climate hope (see section 5.6.2). These emotions emerged as the strongest candidates for driving climate action across the line of

research presented here and served as contrasting experimental conditions in the neuroimaging study (Study 4).

5.3 Evoking emotions related to climate change

Pictures of emotionally charged scenes, such as starving polar bears, blazing wildfires, or malnourished children reaching for clean water, are often used to provoke intense affective responses and action (Feldman & Hart, 2018; Leviston et al., 2014). However, what makes an emotional stimulus effective in promoting meaningful action? Addressing this question requires a componential approach to emotions, a precise specification of appraisal patterns, and a theoretically grounded selection of the format and modality of emotional stimuli (Brosch, 2021).

A few datasets of standardised visual climate-related stimuli have been created and are currently in use. The Affective Climate Images Database (Lehman et al., 2019), the Extreme Climate Event Database (Magalhães et al., 2018), and Climate Visuals (Chapman et al., 2016) each provide climate-themed images, characterised by dimensional properties, such as arousal and valence they evoke. These materials are often ambiguous because the related appraisal structures were not specified. It is challenging to elicit a particular, distinct emotional state with a single picture without additional context (Briesemeister et al., 2014; Harmon-Jones et al., 2017). For this reason, despite their long-standing use in affective science (Lang & Bradley, 2007; Marchewka et al., 2014; Michałowski et al., 2017), images seem insufficient for studying the mechanisms of climate emotion from the appraisal perspective.

Narratives, by contrast, offer greater control over appraisals. News articles, podcasts, and personal stories allow detailed framing and have proven effective in eliciting distinct emotions such as hope, fear, or anger (Myers et al., 2012; Nabi et al., 2018; Wong-Parodi & Feygina, 2021). Narratives guide attention to causal structure, highlight agents' responsibility, and place climate change in personal and social context (Lu & Schuldt, 2015). Narrative transportation theory proposes that reading personal stories promotes experiential processing over analytical thinking (Green & Brock, 2000; Zak, 2015), leading to greater emotional engagement and reduced counter-arguing (Cooper & Nisbet, 2016). Personal stories were found to be more effective than purely informational content at

fostering support for mitigation policies (Morris et al., 2019). Using short stories to elicit emotions defined by sets of appraisals was successfully conducted before to decode distinct emotions from brain activity patterns (Skerry & Saxe, 2015). In that study, an appraisal-based model explained differences between emotions - both in behaviour and in the brain - better than dimensional or basic-emotion models.

High-immersion media such as video, interactive simulations, or virtual reality experiences deliver strong multi-sensory cues and can evoke intense emotions (Cooper & Nisbet, 2016; Klein & Hilbig, 2018; Nicholson-Cole, 2005), but at the cost of the difficulty of standardising low-level audio and visual features. These confounds are critical in experimental settings, especially in neuroimaging research, where control of luminance, contrast, and entropy is essential (Jääskeläinen et al., 2021; Saarimäki, 2021). Their development is also more resource-intensive, even with the rise of generative AI, whose environmental costs are non-negligible (Hosseini et al., 2025). Creating large, naturalistic stimulus sets with precise prompting is more feasible than ever and will likely advance research that requires standardised visual stimuli in the coming years.

Taken together, these considerations suggest that concise, naturalistic text stories provide a favourable balance between ecological validity, experimental control, and resource demands. Importantly, this format allows climate change to be presented as part of everyday experience rather than as an abstract phenomenon (Harris, 2017; van der Linden, 2015).

5.2. Measuring pro-environmental behaviour

Pro-environmental behaviour (PEB) refers to behaviours that reduce harm to or benefit the natural environment (Steg & Vlek, 2009), although different definitions emphasise either the intentions motivating it or its consequences (Lange, 2024). PEB is a heterogeneous class of behaviours that vary in their social context, frequency, and required resources. Existing classifications distinguish, among others, private versus public behaviours, individual versus collective action, habitual versus one-off choices, commissions (acting) or omissions (refraining from behaviour). PEB may also differ in the type of resources contributed, such as money, time, or effort. Climate action, as behaviour specifically aimed at mitigating anthropogenic climate change, constitutes a subset of this broader class of PEB.

Reliable measurement of PEB has been a topic of serious debate in the field. A core issue raised by the researchers is the "value-action gap" (Blake, 1999) or "attitude-behaviour gap" (Kollmuss & Agyeman, 2002), which refers to the discrepancy between intentions and actual behaviour. Declarations and decisions made in hypothetical scenarios are typically poor models of real-life situations (Conner & Norman, 2022; Klein & Hilbig, 2019; Morales et al., 2017). For instance, real donations average 27% less than hypothetical ones (Clements et al., 2015). Self-report declarations can be useful for studying individual readiness to act pro-environmentally. Still, they are less suited to examining the causal mechanisms that underlie actual behaviour or to formulating recommendations for promoting PEB. Despite long-standing calls for more robust and ecologically valid measures of PEB, self-reports are still misrepresented as measures of behaviour (Dablander et al., 2025; Sinclair et al., 2025). This is not an isolated issue: in the *Journal of Environmental Psychology*, 80% of papers published in 2015-2016 relied solely on self-reports of behaviour, intentions and attitudes (Lange et al., 2018). This approach limits the ecological validity of environmental psychology research.

Meaningful measurement of PEB requires a clearly defined and well-operationalised target - a consequential, observable, and quantifiable act that aligns conceptually with one's research question. In recent years, several experimental paradigms have been developed to measure actual PEB (Lange & Dewitte, 2019). Charitable monetary donation tasks capture willingness to forgo private resources for climate protection and are valued for their simplicity and straightforward quantification in currency units; however, their sensitivity can be limited among participants with extremely low or high socio-economic status (Schulreich et al., 2023). When the research design requires repeated instances of the same trade-off between self-interest and climate-interest (e.g., to estimate brain activity across many trials), multi-trial decision tasks are preferable. The Carbon Emission Task (CET; Berger & Wyss, 2021) presents a series of binary choices between self-benefit and climate benefit, thereby mapping a continuous trade-off that can be modelled trial by trial. In contexts where monetary stakes are insufficiently diagnostic, paradigms that require non-monetary investment - time, cognitive or physical effort - such as the Pro-environmental Behaviour Task (PEBT; Lange et al., 2018) and the Work for Environmental Protection Task (WEPT; Lange & Dewitte, 2021) provide a quantifiable measure of PEB. Finally, when the theoretical focus is on decision-making in explicitly

social contexts, paradigms like the Greater Good Game (Klein et al., 2017) and related social-dilemma tasks are more appropriate because they parameterise social cues and feedback from others - features that are orthogonal to the individual trade-off captured by donation or effort tasks. In sum, task selection should be theory-led and aligned with the study goals, design, and technical constraints.

5.3. How do climate emotions impact pro-environmental behaviour?

Even with growing evidence that emotions can influence climate action (Brosch, 2021, 2025; Goldberg et al., 2021), conclusions about the direction and strength of the impact remain mixed (Kühner et al., 2024; O'Neill & Nicholson-Cole, 2009; Vlasceanu et al., 2024). This suggests that emotions cannot be treated as simple behavioural levers (Chapman et al., 2017). Instead, process-oriented models, especially appraisal theories, can prove more useful for identifying the causal role of specific components that constitute various emotions.

According to the aforementioned Component Process Model (CPM), emotions emerge from sequences of appraisals associated with specific action tendencies, physiological arousal, and expressive/regulatory components (Sander et al., 2005, 2018). The same nominal emotion (e.g., “anxiety”) can be followed by different behaviours depending on its appraisal profile: high threat paired with high coping supports solution-focused action, whereas high threat with low coping can lead to avoidance or denial of the problem (Heeren & Clayton, 2026; Kothe et al., 2023; Popova, 2012). Framed in these terms, CPM provides testable predictions for PEB: emotions emerging from appraisals of high relevance and urgency of a possible, relatable situation that relates to moral norms, along with the heightened sense of efficacy and responsibility for coping, should more reliably produce action-oriented tendencies and the physiological activation required for PEB (Geiger et al., 2023; van Valkengoed et al., 2022).

Interestingly, prominent models in environmental psychology formalise the same appraisal types included in CPM, even though they do not explicitly refer to the affective dimension. Some emphasise the role of threat perception and efficacy beliefs (Maloney et al., 2011; Rogers, 1975), others focus on appraisals of certainty of outcome and control (Lerner &

Keltner, 2000), others centre on responsibility and norm congruence (Schwartz, 1977; Stern et al., 1999). These perspectives are compatible with CPM but address just a subset of the appraisal sequence.

A new approach to studying how emotions influence PEB is the use of methods from environmental neuroscience. This field integrates neuroimaging and environmental psychology to examine how brain systems contribute to climate-relevant decision-making and behaviour (Aldern, 2024; Knoch & Wyss, 2026; Kühn, 2024). Neuroimaging provides access to processes not fully captured by self-report or overt behaviour, including rapid affective and regulatory responses that occur during decision-making and remain inaccessible to introspection (Doell et al., 2023; Sawe & Chawla, 2021; Vezich et al., 2017). This is particularly relevant in the climate domain, where emotional stimuli may engage automatic appraisal and regulation processes that shape attention, valuation, and action selection (FeldmanHall & Heffner, 2022). Brain activity measures can be directly compared with traditional indicators of PEB, while providing access to another level of mechanistic understanding. Prior work has shown that brain activity can outperform self-reports in predicting real-world health behaviours and sustainable purchases (Berkman & Falk, 2013; Doell et al., 2023; Falk et al., 2012; Kühn, 2024; Sawe et al., 2022; Todorova et al., 2025). Neuroimaging can be a complementary source of evidence interpreted alongside behavioural, self-report, and contextual data.

The thesis distinguishes between experimentally induced climate emotions and baseline climate emotions. Experimentally induced emotions refer to short-term states elicited by stimuli, whereas baseline emotions refer to relatively stable emotional dispositions toward climate change, measured before the manipulation. This distinction is important because transient emotional states and baseline emotional orientations may influence PEB through partly different mechanisms. The appraisal-based account outlined in this section explains how emotion may shape climate-relevant decisions by altering appraisals of relevance, causality and implications, coping potential and normative significance. However, PEB is shaped not only by situational appraisals but also by more stable, individual attitudes and dispositions, which are explicitly emphasised in many PEB decision-making frameworks (Klößner & Blöbaum, 2010). Individuals differ in baseline climate emotions, which may bias how situational contingencies are interpreted and weighted. Prior work indicates that

self-reported climate emotions are related to pro-environmental intentions (Marczak, 2023). These trait-like differences can be expressed as systematic variation in choice preferences and in sensitivity to costs and benefits across decision contexts.

Within this broader environmental neuroscience framework, the Component Process Model offers a theoretically grounded way to operationalise emotions. Rather than mapping discrete emotions to specific brain regions, the CPM focuses on the coordinated activity of neural systems that underlie appraisal processes (Mohammadi et al., 2023; Sander et al., 2018). This componential approach is well-suited to studying complex climate-related emotions. Despite this conceptual fit, the CPM had not yet been applied to study the brain mechanisms by which emotions influence PEB. Addressing this gap provides a clear point of departure for the present research program.

5.4. Brain mechanisms of climate emotions and climate-relevant decision making

The final part of the introduction provides the rationale for the last study, where the appraisal-based account is extended to brain activity during climate emotion processing and climate-relevant decision-making.

The use of neuroimaging techniques to investigate climate emotions and their influence on PEB is a relatively recent, but promising advancement of environmental psychology (Doell et al., 2023; Knoch & Wyss, 2026; Kühn, 2024). Patterns of brain activity can be more reliable predictors of PEB than self-reports (Doell et al., 2023; Sawe et al., 2022) or behavioural measurements (Sawe, 2019). In practical terms, investigating these complex and context-laden phenomena requires a design that breaks down both “climate emotion” and “pro-environmental behaviour” into more granular processes (Mohammadi et al., 2023; Sander et al., 2018; S. Wang & van den Berg, 2021).

Multiple low-level processes are involved in the processing of climate emotions. CPM assumes a causal role of cognitive appraisals, including assessments of relevance, causality, implications, coping potential, and normative significance, in shaping emotional responses (Sander et al., 2005, 2018). This framework allows emotions to be operationalised as appraisal patterns associated with specific brain activity. Despite promising theoretical support, this approach has so far attracted little direct attention in

neuroimaging research. To my knowledge, only one study examined specific appraisal features in relation to emotion-related brain activity (Skerry & Saxe, 2015), and only one study referred directly to CPM (Mohammadi et al., 2023). No study directly investigating brain correlates of climate emotions using CPM was identified.

Similarly, PEB also requires the coordinated activation of brain networks that compute the costs and benefits of available options, evaluate situational constraints and one's efficacy, represent personal values and social norms, exercise self-control and ultimately generate motor responses (Levy & Glimcher, 2012; S. Wang & van den Berg, 2021). From valuation to the motor output, each stage of PEB generation can be modulated by the appraisals that constitute the current emotional state (FeldmanHall & Heffner, 2022; Lerner et al., 2015). An important open question is which combinations of appraisals are most likely to elicit climate emotions and encourage PEB in the real-world contexts (Campbell et al., 2023; Contreras et al., 2023; Geiger et al., 2023). The CPM theoretical approach and functional neuroimaging can bring us closer to answering these questions.

5.4.1. Neuroimaging of the appraisal patterns

CPM proposes that emotions arise from appraisal processes that evaluate events along several dimensions, which together shape subjective experience and guide motivation and behaviour (Sander et al., 2005; Scherer, 2009). This framework may help explain why studies that manipulate emotion without specifying the underlying appraisal profile often yield mixed results (Kothe et al., 2023; Lange & Truysens, 2022; Popova, 2012; Scherer & Moors, 2019). Applied to climate communication, an appraisal-based approach may clarify which cognitive and biological processes make emotional messages more likely to encourage PEB. The following sections describe the major appraisal families proposed by CPM, their relevance to climate change, their proposed correlates in brain activity, and the available evidence from climate-related and pro-environmental decision-making research (Huang et al., 2018; Mohammadi et al., 2023; Saarimäki et al., 2022).

Relevance

According to CPM, each emotional stimulus is first appraised for its relevance to survival or other vital goals of the individual (Sander et al., 2018; Scherer, 2009). Core components of relevance appraisal include stimulus novelty, intrinsic pleasantness, and goal

congruence. While early theoretical formulations and some neurophysiological data (e.g., ERP latency patterns) suggest a sequential processing of these components (Gentsch et al., 2015), more recent work recognises that appraisals may occur in a partially parallel and recursive manner, shaped by contextual and individual factors (Scherer & Moors, 2019; Scherer, 2019). Relevance appraisal is important in the context of climate change, because climate-related information can be experienced as threatening, emotionally salient, pleasant or unpleasant, and more or less personally consequential.

At the brain level, the amygdala is widely proposed as a core structure involved in relevance detection (Stussi & Sander, 2024; Varkevisser et al., 2024). Additional evidence suggests that different components of relevance appraisal recruit partially overlapping systems.

For example, novelty processing has been linked to a distributed network involving the hippocampus and amygdala, with additional recruitment of lateral and orbitofrontal regions and temporoparietal cortex (Brosch & Sander, 2013; Ranganath & Rainer, 2003). Intrinsic pleasantness has been linked to patterns of brain activity related to affective value and valence encoding: positively valued stimuli preferentially engage ventromedial prefrontal cortex (VMPFC) and anterior ventral striatum, whereas unpleasant and aversive states more frequently engage a network centred on the amygdala, anterior insula, dorsal anterior cingulate cortex (ACC) and periaqueductal grey (Bartra et al., 2013; Lindquist et al., 2016; Schimmelpfennig et al., 2023). Goal congruence has been linked to regions involved in conflict monitoring and cognitive control, particularly the ACC and dorsolateral prefrontal cortex (DLPFC) (Brosch & Sander, 2013).

Findings from pro-environmental decision-making are broadly consistent with the proposed relevance network. The prospect of buying an eco-friendly product has been associated with increased activity in the ventral striatum (Sawe et al., 2022). Activation in ventral striatum and VMPFC predicts pro-environmental purchasing choices; for example, people may be willing to pay more for eco-friendly products and rate fair-trade chocolate as more pleasant (Enax et al., 2015; Linder et al., 2010). On the other hand, thinking about environmental destruction increases anterior insula activity (Sawe & Knutson, 2015). Reward-related responses may be attenuated when the benefits of eco-friendly choices are represented in abstract rather than personally meaningful terms, despite self-reported pro-environmental orientation (Todorova et al., 2024). These findings suggest that framing

climate change as personally relevant and PEB as intrinsically rewarding should increase the likelihood of action.

Causality and Implications

Another class of appraisals concerns causality and implications (Sander et al., 2005, 2018; Scherer, 2009). Causality appraisals focus on responsibility and intentionality and are important because climate change is widely understood as human-driven, and rejecting anthropogenic causality is a form of climate denial (Hornsey & Lewandowsky, 2022). Implication appraisals concern the likely consequences of climate change and one's own actions, including those for temporally distant beneficiaries, such as future generations.

At the brain level, inferring agency and assigning responsibility draws on brain systems involved in understanding others' perspectives and intentions. The cognitive component of this process, often referred to as mentalizing, recruits the medial prefrontal cortex, precuneus, and temporoparietal junction (TPJ) (Schurz et al., 2021). These regions are activated when thinking about others' motives or judging the morality of their actions (Kühn, 2024; Parkinson et al., 2011). The affective component, or empathy, engages the anterior insula and anterior cingulate cortex, particularly when people feel personally responsible for harm (Cui et al., 2015) or engage in altruistic acts (Lockwood et al., 2022; Schurz et al., 2021). Consistently, prosocial behaviour can be predicted by activity in both the TPJ and the right anterior insula, suggesting the integration of cognitive and affective processes during the evaluation of others' actions (Tusche et al., 2016). In line with this, Brosch and Sander (2013) proposed that causality appraisals rely on a network centred on TPJ, precuneus, dorsomedial prefrontal cortex (DMPFC), and pre-supplementary motor area (pre-SMA), with additional recruitment of insula and motor-related regions when self-agency is involved.

A distinctive challenge for considering the implications of climate action lies in the temporal distance of its beneficiaries, such as future generations (Polasky & Dampha, 2021). Implication appraisals have been linked to brain regions implicated in episodic future thinking, valuation, and temporal projection, including medial prefrontal cortex, posterior cingulate cortex (PCC), and anterior VMPFC (Brevers et al., 2021; Brosch et al., 2018; DiNicola et al., 2020; Sawe & Knutson, 2015; Wang et al., 2025). Recent

meta-analytic evidence further suggests that future-oriented cognition draws on dynamic combinations of large-scale brain systems, including the Default Mode Network (DMN) for future event simulation and salience and control networks for goal-directed planning (Cona et al., 2023).

Empirical work in climate-related and pro-environmental contexts is broadly consistent with this account. Decisions framed as consequential for future generations engage brain regions related to mentalizing (TPJ, DMPFC) and cognitive control (ACC, DLPFC), consistent with CPM accounts of implication appraisals (Baumgartner et al., 2023; Sander et al., 2018). Recent study found that sacrificing for the environment elicited stronger activation in TPJ and DMPFC (Le Houcq Corbi et al., 2025). Larger TPJ volume predicts higher carbon-offsetting donations (Baumgartner et al., 2025), and its stimulation increases sustainable behaviour directed at future beneficiaries (Langenbach et al., 2022). Taken together, these findings suggest that attributions of human agency, when combined with vivid appraisals of future consequences, may support PEB.

Coping

The third family of appraisals concerns coping, that is, the perceived ability to exert influence on the environment through one's own or collective action and adjust to inevitable changes (Sander et al., 2018). In CPM, coping appraisals integrate earlier evaluations of relevance and implications with beliefs about control and efficacy, although the model leaves the exact neural implementation relatively open. Coping is especially important in the context of climate change, where many outcomes are perceived as distant, uncertain, and impersonal, and are therefore often associated with low perceived behavioural control (Kühn, 2024). Even when the threat is near, certain, and personal, coping appraisals may still remain weak, shifting behavioural tendencies toward defensive responses and avoidance rather than action.

Sander et al. (2018) note that hardly any neuroimaging research has directly examined coping as a distinct appraisal criterion, so brain mappings in this domain remain largely inferential. Evaluation of one's coping potential requires self-referential thought, often associated with activity in midline regions of the DMN, such as VMPFC and PCC (Daviddi et al., 2023; DiNicola et al., 2020; Kuzmanovic et al., 2016). In the context of climate change, these brain activity patterns can be cautiously interpreted as possible brain

mechanisms of coping appraisals. Individuals who reported greater perceived capacity for positive behavioural change showed stronger activation in the VMPFC and hippocampus when imagining sustainable behaviours (Brevers et al., 2021). Conversely, thinking about the cessation of unsustainable habits preferentially recruits the right DLPFC and shows negative coupling with the hippocampus, possibly indicating inhibitory control over current habits (Brevers et al., 2021; Wang et al., 2025). These findings are broadly consistent with the view that stronger perceived efficacy and more concrete action opportunities may be important for motivating PEB.

Normative significance

Compatibility of one's personal and social norms with the appraised event is the final appraisal class postulated by CPM, called normative significance (Sander et al., 2005). Climate change is a deeply polarising social issue, with marked ideological and value-based divides in risk perception, responsibility attributions, and preferred responses (Czarnek et al., 2025; Kácha et al., 2022; Poortinga et al., 2019). To many people, PEB overlaps with prosociality and is seen as a personal obligation (Zaremba et al., 2022). Others do not construe PEB as a moral issue; some underestimate or misinterpret the consequences of climate change; some lack trust in climate science and regulation; others hold values and ideological commitments that downplay environmental protection (Cipriani et al., 2022; Haltinner & Sarathchandra, 2018; Norgaard, 2006). Nevertheless, most people are aware of societal expectations regarding PEB and tend to comply with them, especially in public contexts where social norms are salient (Farrow et al., 2017).

At the brain level, normative significance appraisals seem to be processed by a network implicated in moral judgment. Reviews of human neuroimaging studies point to a central role of the temporal pole, VMPFC, amygdala, dorsal striatum, and DLPFC (2013; Sander et al., 2018). To represent the moral perspective-taking aspect of normative appraisal, these regions interact with TPJ/angular gyrus and PCC/precuneus, which support understanding others' perspectives and evaluating one's own behaviour in a moral context (Schurz et al., 2021). Current neuroimaging evidence further suggests that events appraised as norm-congruent or morally exemplary draw more strongly on valuation and self-related moral reflection, whereas events appraised as norm-violating engage processes related to moral condemnation and responsibility attribution; these differences are best characterised

as graded shifts within shared moral-evaluative networks, but do not engage distinct brain regions (Bellucci et al., 2020; Bzdok et al., 2012; Cutler & Campbell-Meiklejohn, 2019; Lockwood et al., 2022).

Empirical work on prosocial and environmental decisions is consistent with this characterisation. In a charitable giving task, participants with more egoistic values donated less to charity and showed greater activation in the amygdala and ventral striatum when keeping money for themselves, indicating that value-based preferences modulate how norm-relevant choices are evaluated (Brosch et al., 2012). In the context of PEB, choices with explicit information on environmental impact recruit a similar appraisal network: when people evaluate consumer products whose life-cycle environmental costs are made salient, they shift their choices towards the less harmful options, and this shift is accompanied by increased activation in DMPFC and temporal regions associated with moral cognition and social understanding (Goucher-Lambert et al., 2017). Parallel activation in systems implicated in self-referential thought and mentalizing likely indexes anticipation of how others will view one's choice and the interpersonal implications of acting (or failing to act) sustainably. Within CPM, this pattern can be interpreted as an increase in normative significance. Although the same DMPFC-temporal system appears in appraisals of "Causality/Implications", its functional role here is different. Rather than judging who caused harm or who should act, the network serves to assess normative fit - how the response choice aligns with internalised social norms and expected evaluations by others.

5.4.2. Appraisal-related brain activity in specific climate emotions

In the following section, a CPM-based decomposition of climate anger and climate hope is used to illustrate the appraisal-based approach to climate emotions adopted in this thesis. The appraisal patterns presented in Table 1 are expanded by linking them to brain regions whose activity may be associated with the processing of these emotions.

Both climate anger and hope arise when climate-related information is appraised as novel, personally relevant, and centred on the behaviour of human actors, rather than on "climate change" itself. In both cases, the events are seen as consequential for future outcomes and as socially and normatively significant situations in which harm or benefit is at stake (Harth et al., 2013; Kleres & Wettergren, 2017; Landmann & Hess, 2017). Climate anger

and hope are also both approach-oriented tendencies and motivations to influence collective responses to climate change (Geiger et al., 2023; Stanley et al., 2021).

Despite these convergences, climate anger and hope differ in other appraisal dimensions. The experience of anger and hope are contrasting in terms of valence (or, in CPM terms, intrinsic pleasantness). In causality and implication appraisals, climate anger typically highlights harm, injustice and loss caused by the out-group, whereas climate hope highlights anticipated benefits, improvement and the efficacy of the in-group (Landmann & Hess, 2017; Ojala & Chen, 2024). In coping appraisals, anger tends to promote confrontation and punitive action to restore balance, whereas hope inspires enthusiastic and collective problem-solving (Geiger et al., 2023; Gregersen et al., 2025). In normative appraisals, climate anger is directed at actors perceived as violating moral and social norms, whereas climate hope often focuses on actors or initiatives seen as exemplary in upholding such norms (Kleres & Wettergren, 2017).

The field has long debated whether positive or negative climate emotions are more conducive to PEB (Hurst & Sintov, 2022; Kühner et al., 2024; O'Neill & Nicholson-Cole, 2009; Schneider et al., 2021). Although anger and hope are characterised by contrasting valence, specifying them in terms of CPM appraisal patterns allows one to move beyond the dimensional approach. In the present dissertation, the design is not intended to isolate the unique contribution of any single appraisal dimension, independently of other co-activated appraisals (Campbell et al., 2023). Rather, functional MRI can be used to examine which distributed brain networks are engaged by these appraisal configurations and how their engagement relates to climate-relevant choices.

Climate anger

Climate anger manifests as moral outrage directed at individuals or institutions that knowingly contribute to the climate crisis (Gregersen et al., 2023). Across climate emotions, anger appears particularly action-oriented and, compared with anxiety and sadness, shows the strongest temporal links to subsequent PEB (Contreras et al., 2024; Stanley et al., 2021). Through the lens of the CPM framework, climate anger can be characterised by negative intrinsic pleasantness, as climate change is evaluated as threatening, harmful and obstructive to personal and collective goals (Zaremba et al.,

2022). The relevance appraisal of threat that characterises climate anger is expected to involve the amygdala and anterior insula, regions consistently implicated in detecting motivationally significant and potentially harmful events (Sander, 2025; Sander et al., 2003).

Climate anger also depends strongly on appraisals of causality and implications. Anger directed at specific out-groups predicts participation in climate protest, support for punitive climate policies (Gregersen et al., 2025; Kleres & Wettergren, 2017; Sabherwal et al., 2021; Stanley et al., 2021; Zaremba et al., 2022). By contrast, when implication appraisals remain diffuse and responsibility is attributed to abstract entities such as “humanity” or immutable human nature, anger loses its motivational potential and is more likely to lead to disengagement (Gregersen et al., 2023). Motives and actions of identifiable actors, such as political leaders, corporations, or economic systems, are represented through causality appraisals that attribute agency and responsibility for climate harm (Marczak, Winkowska, et al., 2023). Recognition that the consequences of climate change disproportionately affect those least responsible for global emissions may further amplify the motivational significance of anger (Landmann & Hess, 2017). These appraisal processes have been linked to a distributed network including the temporoparietal junction and angular gyrus, PCC/precuneus, DMPFC, ACC, and pre-SMA (Ashar et al., 2017; Brosch & Sander, 2013; Gentsch et al., 2015; Kédia et al., 2008; Khoudary et al., 2022; Parkinson et al., 2011).

Coping appraisals shape perceived efficacy and thereby support action taking. In the case of climate anger, coping may be appraised as achievable through justice restoration, either via collective action, political mobilisation, or punishment and regulation of responsible agents (Stanley et al., 2021; Zaremba et al., 2022). When individuals believe that such corrective actions are feasible, anger is more likely to translate into sustained engagement (Gregersen et al., 2025). The collective coping dimension is important because anger may become action-oriented not only through individual efficacy, but also through perceived shared motivation and expectations that others are prepared to act (Sabherwal et al., 2021). This action-oriented profile also makes climate anger a plausible candidate for influencing value-based climate decisions when personal gain must be weighed against climate protection. The brain basis of coping appraisals remains relatively understudied, but available evidence suggests involvement of regions supporting episodic future thinking,

self-referential processing, and cognitive control, including VMPFC, hippocampus, PCC/precuneus, and DLPFC (Brevers et al., 2021; Sander et al., 2018).

Finally, climate anger is characterised by negative normative significance appraisals; a perceived incompatibility between the appraised situation and deeply held moral and social norms is necessary for the emergence of moral outrage, the subjective affective state associated with climate anger. Neuroimaging studies indicate that perceived moral violations, particularly those involving harm and injustice, engage evaluative and perspective-taking systems centred on the temporal pole, VMPFC, amygdala, dorsal striatum, DLPFC, and TPJ/angular gyrus (Kédia et al., 2008; Khoudary et al., 2022; Parkinson et al., 2011; Sander et al., 2018).

Climate hope

Climate hope is a complex emotion, adjacent to awe, enthusiasm and anticipation; it emerges when an individual realises that thanks to the efforts of ordinary people, the future trajectory of the climate crisis is still malleable, and a positive outcome is possible, but not certain (Geiger et al., 2023; Sabherwal & Shreedhar, 2022). Its motivational quality depends on how that possibility is construed. “False hope”, the conviction that climate change will resolve itself or that personal sacrifice is unnecessary, is a form of disengagement and predicts lower mitigation efforts (Geiger et al., 2023). In contrast, “constructive hope” combines an acknowledgement of risk with the belief that collective agency and technological or policy solutions remain viable (Ojala, 2015). Observing successful efforts to combat climate change, especially those undertaken by relatable in-groups, increases constructive hope (Zaremba et al., 2022). Evidence indicates that constructive hope is positively related to PEB, policy support, and political engagement (Feldman & Hart, 2018; Ojala & Chen, 2024). Interventions that strengthen appraisals of importance, goal congruence, positive future expectation and efficacy beliefs without downplaying threats amplify constructive hope, whereas messages that rely on empty optimism risk fostering denial-based complacency (Chadwick, 2015; Marlon et al., 2019). Hope is, therefore, motivational only when positive future outcomes are appraised as important, desirable, and realistically achievable through action.

There is currently no neuroimaging work directly addressing climate hope, but related components such as awe, optimism, and a sense of efficacy have been studied using neuroimaging tools. Within a CPM framework, hope can be characterised as a positively valenced emotion grounded in favourable evaluations of future outcomes. Positive valuation is consistently associated with activity in the VMPFC and ventral striatum (Bartra et al., 2013; Kuzmanovic et al., 2016; Sander et al., 2018). Causality and implications appraisals recruit the network centred on the TPJ/angular gyrus, PCC/precuneus, DMPFC, ACC, and pre-SMA, with the VMPFC contributing at this appraisal stage to the positive valuation of action outcomes and anticipatory pleasure (Brosch et al., 2018; D'Argembeau et al., 2008; Luo et al., 2017). Similarly to climate anger, high perceived efficacy (coping appraisal) is also constitutive of climate hope; this appraisal engages systems supporting episodic future thinking, self-referential processing, and cognitive control, including the VMPFC, hippocampus, PCC/precuneus, and DLPFC (Brevers et al., 2021; Sander et al., 2018). Additionally, systems implicated in optimism and future-oriented cognition include the ACC and inferior frontal gyrus, which have been associated with monitoring, cognitive control, and the regulation of goal-directed behaviour (Erthal et al., 2021). Finally, the compatibility of appraised events with personal and moral values further engages the temporal pole, amygdala, dorsal striatum, DLPFC, and VMPFC, supporting moral perspective-taking and self-other evaluation (Cutler & Campbell-Meiklejohn, 2019; Immordino-Yang et al., 2009). Together, these CPM-consistent appraisal processes approximate how climate hope can integrate positive valuation, optimistic future expectancy, perceived efficacy, and normative alignment.

5.4.3. Brain and cognitive processes related to emotionally motivated PEB

The general connections between emotion and decision-making have been extensively studied (Lerner et al., 2015). However, the literature on specific climate emotions and their effects on PEB remains scarce. Given this scarcity, hypotheses can be informed by related evidence from prosocial decision-making (Bellucci et al., 2020; Kühn, 2024; Le Houcq Corbi et al., 2025) and emerging neuroimaging research on PEB, recently summarized by Knoch and Wyss (2026).

Climate-related PEB is a socially relevant act related to multiple appraisals. PEB depends on representing the choice as a salient event; evaluating immediate gains and losses; anticipating long-term consequences for oneself and other people; and assessing the compatibility of one's actions with social and moral standards. Based on this view, PEB should engage a broad network of regions that support affective salience, mentalising, self-referential moral evaluation, value integration, and control over action (Bellucci et al., 2020; Guizar Rosales et al., 2022; Le Houcq Corbi et al., 2025).

Prosocial behaviours, such as punishing norm violations or donating to a charity, recruit brain networks implicated in valuation and reward processing, as well as regions responsive to social outcomes (Wang & van den Berg, 2021). Evidence from altruistic giving tasks indicates that VMPFC, ACC, and insula form a core network for integrating multiple choice attributes during costly prosocial decisions (Cutler & Campbell-Meiklejohn, 2019; Yang & Li, 2025). Emotional arousal during decision-making heightens activity in the amygdala, anterior insula, and anterior- and mid-cingulate cortices (ACC/MCC), while the ventral striatum and VMPFC encode and integrate subjective value signals that guide action (De Martino et al., 2006; Levy & Glimcher, 2012; Rhoads et al., 2021).

Evidence from classic economic games further demonstrates that emotional context modulates choice. Early research attributed the frequent rejection of unfair offers in social games to the induction of righteous anger (Pillutla & Murnighan, 1996), with brain recordings implicating anterior insula and cingulate activity (Sanfey et al., 2003). However, attributing such effects to anger alone proved unwarranted; compared with neutral or happy inductions, sadness (Harlé & Sanfey, 2007) and disgust (Moretti & di

Pellegrino, 2010) also increase rejections of unfair offers. Accordingly, more recent research focuses on the constitutive appraisals shared between emotions (FeldmanHall & Heffner, 2022).

Emotional framing of PEB can increase the affective salience of climate consequences, make the impact of decisions more prominent, and heighten awareness of conflicts between egoistic choices and personal norms. Exposure to emotional climate stimuli is expected to modulate activity in appraisal-related networks involved in decision-making. Affective salience signals are expected to arise in the amygdala, anterior insula and dorsal ACC/MCC, which respond to emotionally charged events and to conflict between competing goals (De Martino et al., 2006; Rhoads et al., 2021; Sorella et al., 2021). Mentalising and agency-related processing should recruit TPJ, precuneus and DMPFC, which are involved in representing others' perspectives, attributing responsibility, signalling moral conflict and considering the impact of one's actions on other people and future generations (Baumgartner et al., 2023; Le Houcq Corbi et al., 2025; Obeso et al., 2018; Schurz et al., 2021). Appraisals of the moral significance of choices further demand mentalising, self-referential thinking, and the projection of post-decision affective states, engaging the posterior cingulate cortex, precuneus, and temporal pole (Bzdok et al., 2012; DiNicola et al., 2020; Olson et al., 2007). Valuation and integration of multiple attributes of choices involve the VMPFC and ventral striatum, which are responsible for encoding the subjective value of options (Bellucci et al., 2020; Lopez-Gamundi et al., 2021; Shapiro & Grafton, 2020). Finally, a number of distributed structures, including the striatum, pre-SMA, and DLPFC, support action selection, preparation of the chosen response, and cognitive control (Baumgartner et al., 2019; Brevers et al., 2021; Cieslik et al., 2024; Vural et al., 2024).

Resolving conflicts between personal gain and environmental benefit requires self-control. Therefore, pro-environmental choices are expected to engage the lateral prefrontal cortex (especially the DLPFC) more strongly than self-interest choices. The DLPFC supports top-down regulation of value-based decisions, inhibits impulsive or selfish responses, and tracks long-term goals (Baumgartner et al., 2019; Carlson et al., 2025; Nash et al., 2023). Functional and structural connectivity within the lateral prefrontal cortex has been shown to predict everyday PEB and engagement in climate action (Baumgartner et al., 2025; Guizar Rosales et al., 2022).

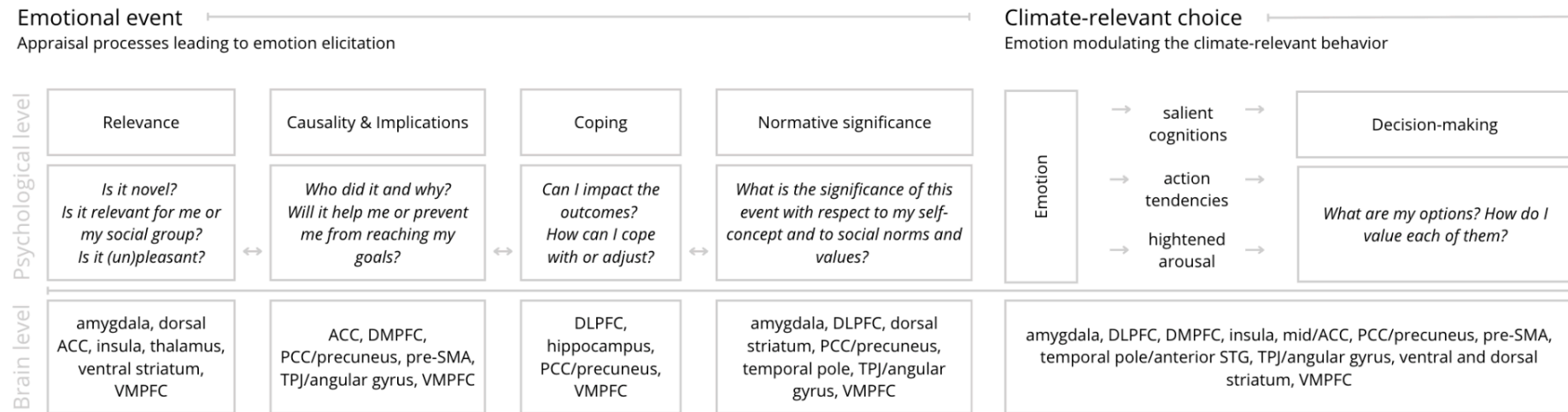


Figure 2. A conceptual model linking appraisal processes, emotion, and climate-relevant decision-making proposed in this thesis. This model integrates psychological appraisal dimensions based on CPM (top row), associated brain activity inferred from existing neuroimaging studies (bottom row), and hypothesised pathways through which emotion may shape climate-relevant decision-making. The final column illustrates how emotion may modulate decision-making by altering salient cognitions, arousal, and action tendencies. Bidirectional arrows indicate the recursive and interactive nature of these processes.

5.5. General aims and hypotheses

The theoretical and empirical literature reviewed above points to an important gap. Climate emotions are increasingly recognised as relevant to pro-environmental behaviour, but the mechanisms linking them to action remain insufficiently understood. Much of the existing research has relied on self-report measures, broad emotion categories, or correlational designs. Less is known about how specific climate emotions are constructed through appraisal processes, how they can be elicited experimentally in a controlled but ecologically valid way, whether they influence consequential PEB, and how they are represented in brain activity. In particular, there is limited evidence connecting appraisal-based theories of emotion with behavioural and neuroimaging measures of climate-relevant decision-making.

The general aim of this dissertation was to examine climate emotions as appraisal-based processes and to test how they relate to pro-environmental behaviour at experiential, behavioural, and brain activity levels. The dissertation addressed four overarching questions. First, how do people describe, interpret, and regulate emotions related to climate change in everyday life? Second, can short climate-change narratives be developed and validated as standardised stimuli that elicit distinct climate emotions? Third, do experimentally induced climate emotions increase consequential forms of PEB? Fourth, are climate emotions associated with brain activity during the processing of climate-related emotional narratives and during climate-relevant decisions?

The empirical programme was designed as a sequence of four studies, in which each stage informed the next. Study 1 used qualitative interviews to map climate emotions as they appeared in participants' own accounts. This study provided an empirically grounded description of the contexts, appraisals, coping responses, and action tendencies associated with climate emotions. Study 2 used this qualitative content, together with the existing literature and the Component Process Model, to develop and validate the Emotional Climate Change Stories, a standardised set of short narratives designed to elicit specific climate emotions. Study 3 then used these stimuli in behavioural experiments to test whether induced climate emotions motivate PEB. Study 4 extended this logic to functional

neuroimaging by examining whether climate anger and climate hope recruit appraisal-related brain regions during story reading and whether prior emotional manipulation modulates behavioural and brain responses during climate-relevant decisions.

Across the programme, the set of emotions was progressively narrowed as the methods became more targeted. Study 1 broadly mapped the range of climate emotions reported in interviews. Study 2 focused on five emotions selected from the literature and from CPM-based action-tendency criteria: anger, anxiety, compassion, guilt, and hope. Its validation identified anger, compassion, and hope as the most specific categories, which were therefore used in the behavioural experiment in Study 3. Study 4 further focused on anger and hope because they were theoretically central, formed a clear contrast in valence and appraisal structure, and allowed a sufficiently powered between-group fMRI design.

At the programme level, the central expectation was that climate emotions would not operate as simple positive or negative affective states, but as complex configurations of appraisals concerning relevance, causality, implications, coping potential, and normative significance. It was therefore expected that emotional climate narratives would engage brain regions associated with appraisal-related processing, including regions involved in salience, social meaning, self-referential evaluation, future-oriented thought, valuation, and cognitive control. It was also expected that emotions with clear action tendencies, especially anger, hope, and compassion, could increase pro-environmental behaviour relative to neutral conditions. Finally, because stable climate emotions may be more closely linked to values, identity, and habitual engagement than briefly induced emotional states, the dissertation also examined whether baseline climate emotions predicted climate-relevant choices and choice-related brain activity.

Together, the four studies form a research programme combining qualitative inquiry, stimulus development and validation, behavioural experimentation, and functional neuroimaging. This structure made it possible to move from the description of climate emotions as lived experiences, through their experimental elicitation, to tests of their behavioural and neural correlates. The following chapters report this sequential programme.

6. STUDY 1. MAPPING CLIMATE EMOTIONS

6.1 Rationale

The qualitative study that initiated this research programme had a straightforward purpose: to identify topics that spontaneously emerge in conversations about emotions related to climate change, to understand how these emotions are named, experienced, and regulated in everyday life (Zaremba et al., 2022). Environmental psychology had produced numerous surveys and scales measuring concern, anxiety, or willingness to act, but the field lacked a detailed, empirically grounded account of how people construct and make sense of their climate emotions. Without such an account, later attempts to operationalise climate emotions for experimental purposes would risk imposing categories that do not reflect how these emotions are actually organised.

Study 1 therefore set out to identify the contexts, emotion labels, appraisals, coping responses, and action tendencies associated with climate emotions in a Polish sample of highly concerned individuals. A qualitative approach was chosen because the aim was exploratory: rather than testing whether a predefined set of emotions was present, the study examined how participants themselves described the structure of their climate-related emotional experience. The analysis was guided by an appraisal-based perspective, treating climate emotions as arising from evaluations of climate-related events in relation to personal goals, values, agency, and social meaning.

The findings from Study 1 provided an empirical basis for the next stage of the research programme. In particular, they informed the selection of emotion categories and the development of naturalistic stimuli designed to elicit climate emotions through specific appraisal patterns.

6.2. Method

6.2.1 Participants

Forty Polish-speaking adults who self-identified as strongly concerned about climate change participated in semi-structured, in-depth interviews. A total of 162 volunteers signed up through an online form, of whom 29 were excluded due to incomplete data (e.g.,

missing contact information). Purposive sampling was used to achieve diversity across gender, age, place of residence, educational background, and engagement with climate-related activities (including professional involvement, activism, and parenthood). Additionally, given prior research indicating that individuals professionally engaged with climate issues (e.g., non-governmental organisation (NGO) workers, scientists, and climate activists) tend to report stronger emotional responses to climate change (Kleres & Wettergren, 2017; S. Wang et al., 2018), such participants were also included in the sample. The final sample consisted of 19 men and 21 women, aged 18 to 82 years ($M = 37.38$, $SD = 16.59$). Participants were recruited through social media, email campaigns, and word of mouth. Participation was voluntary and remunerated. Sample characteristics are summarised in the Supplementary Materials (Table S1).

6.2.2. Procedure

Data were collected between March and May 2021. The interviews followed a conversational format (Kvale & Brinkmann, 2009), allowing narrations to evolve naturally rather than being constrained by a fixed structure. To facilitate discussions, interviewers used a semi-structured guide based on materials from Marczak et al. (Marczak, Winkowska, et al., 2023) and a graphical representation of Plutchik's Wheel of Emotions (Plutchik, 2001) in case participants needed help naming and clarifying emotion concepts. If necessary, interviewers encouraged participants to describe, in detail, situations in which they had experienced these emotions.

All interviews were conducted remotely via video conferencing or phone, audio-recorded with consent, and lasted between 28 and 152 minutes ($M = 71.95$, $SD = 24.30$). The core research team met regularly to assess data saturation. After 40 interviews, all interviewers agreed that additional sessions would not yield new relevant insights. The core research team consisted of four trained interviewers who received weekly supervision from an experienced psychotherapist. These sessions allowed interviewers to reflect on how their own experiences of climate change might have influenced the interviews (Braun & Clarke, 2019).

6.2.3. Data analysis

Interview audio recordings were anonymised by removing fragments containing identifying data and modifying the recordings' sound properties. The recordings were transcribed verbatim by professional transcriptionists and the interviewing team. MAXQDA 2020 (VERBI Software, 2022) was used for data annotation.

Data analysis followed a multi-step thematic approach (Braun & Clarke, 2006). First, each interviewer independently came forward with a proposal of a coding system based on two interviews of their choice. These initial codes were compared and discussed to establish a shared understanding of the final coding system. All interviewers contributed to refining the coding system and could suggest modifications if important topics were missing. Lastly, each interview was double-coded by at least two interviewers, allowing sentences or paragraphs to be assigned multiple codes. In cases of coding inconsistency, discrepancies were discussed and agreed upon within the interviewing team. Finally, clear definitions and names for each theme were proposed. The methodological details are reported according to the Consolidated Criteria for Reporting Qualitative Research (Tong et al., 2007). The study protocol was approved by the SWPS University Research Ethics Committee (approval no. 2021–52-12).

6.3 Results

The thematic analysis led to the creation of a hierarchical structure of themes that can be meaningfully overlaid on the appraisal processes proposed by the Component Process Model (CPM). Each theme was organised around a pair of opposing perspectives that generated contrasting appraisals and emotional responses (see Figure 3).

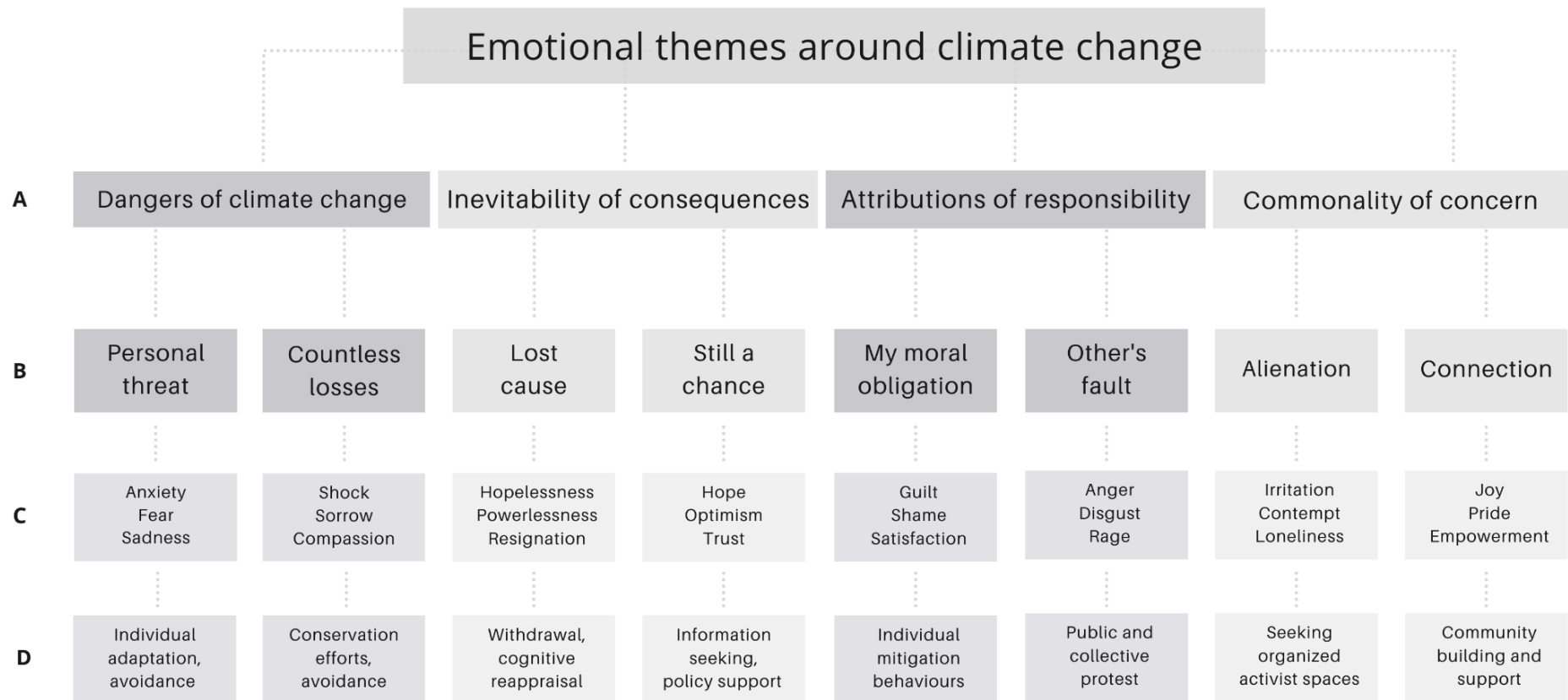


Figure 3. Four main emotional themes around climate change (A) encompass opposing appraisals (B), emerging emotion (C) and reported coping and action tendencies (D).

Dangers of climate change. Climate change was repeatedly appraised as relevant, salient and urgent, whether as a personal or collective threat. Its implications were seen as negative and serious, affecting humans, animals and nature as a whole. Personal relevance appraisals generated persistent anxiety and a sense of undermined safety, often accompanied by avoidance of climate-related news as a coping strategy. Participants who focused on harm to others, including distant species and landscapes, reported feeling deep sadness and compassion, as well as a drive towards conservation activities. A 53 y.o. male participant said:

"So many species of animals and plants don't have habitats anymore. When I see the soil turning into dust, blown away by the wind I have a feeling that something is dying in front of my eyes. (...) In the name of what? (...) This is a bit like, I don't know, a drug addict, for example, who destroys their own body day after day in order to feel good for a little while longer. And we take part in this, basically, whether we like it or not, which is even more sad."

Attribution of responsibility. Appraisals of who is responsible for climate change were a central source of intense moral emotions. When participants appraised climate change as a consequence of their own choices, guilt and shame about their own shortcomings emerged, and when they behaved in line with their pro-environmental values, they reported a sense of satisfaction or 'warm glow' (Hartmann et al., 2017). Several participants described a cycle in which guilt motivated sustainable actions, but relief was short-lived, as individual effort was perceived as insufficient at the systemic level. When participants mentioned their perceptions of political leaders, corporations, industry and media, they appraised them as responsible for the climate crisis, immoral, antisocial and short-sighted. Such appraisals elicited moral outrage and anger, as exemplified with the words of a 32 y.o. woman:

"It is not alright to blame only individuals for what's happening, without taking into consideration the political context of where these people live, in what conditions, in what region of the world and so on. It's not alright that everything is being inverted, and that corporations and neoliberalism basically exploit such environmental and climate change discourse in order to instill a sense of guilt. I don't accept it. I just don't. That's what I don't agree with because I think that's distorting the facts, reversing the truth."

Inevitability of consequences. Awareness of continued greenhouse gas emissions despite collective efforts led many participants to appraise climate change as an irreversible catastrophe. This appraisal produced hopelessness, resignation, and in some cases physical symptoms such as fatigue and emotional numbness. However, many participants simultaneously maintained a fragile sense of hope grounded in concrete evidence of progress, particularly youth-led activism and specific technological or policy advances. Participants who had a strong sense that they could still influence outcomes persisted in climate action even while holding pessimistic beliefs about overall trajectories, often framing this as a moral rather than strategic choice. A 23 y.o. female climate activist said:

“If not now, then never. And if we do not do it, then no one will. I know that activists are somewhat susceptible to illusions of omnipotence. But inaction... I despise inaction. That no matter what, even if it [confrontation with police during climate protests] is unpleasant and even if I am scared, I still have to do it, because otherwise I will not be able to achieve peace of mind and I will lose all self-respect. This also helps me overcome negative emotions.”

Commonality of concern. Participants who felt isolated in their climate concern experienced loneliness, fatigue from social conflict, and damaged relationships. Those who found community with others who shared their concerns reported solidarity, energy, and an increased sense of collective efficacy. Their own concerns also appeared more grounded and relevant. Whether concern felt shared or solitary shaped participants' coping appraisals and their belief that collective action could make a difference. Observation of others' engagement or lack thereof also shaped the appraisals of normative significance, signalling social norms and moral meaning of the inaction or mobilisation of others. A 20 y.o. man said:

“In many cases people close to me do not support me. This disapproval... also leads to sorrow and grief. And the despair we talked about earlier. I can see it now. Yes. Not climate change by itself, but the disapproval... Realising that other people often think in ways quite opposite to mine. And that people that are close to me do not support me in my actions.”

6.4. Discussion

Study 1 showed that climate emotions identified in the interviews can be meaningfully mapped onto the appraisal classes proposed by the Component Process Model (Sander et al., 2018). The contrast between personal threat and harm to others reflected different configurations of relevance appraisal, depending on whether climate change was evaluated as a direct danger to one's own goals or as a source of suffering for others. The tension between lost cause and remaining hope was organised around implication appraisals, including assessments of future consequences and whether positive outcomes remain possible. Attribution of responsibility to oneself or to external agents reflected causality appraisals, that is, evaluations of who caused harm and who should act. Finally, whether climate concern was experienced as shared or isolated shaped coping appraisals by altering perceived social support and collective efficacy, and shaped normative significance by changing what counted as a socially meaningful response.

The study also showed that climate emotions are not stable or clearly separable states. Participants frequently described ambivalence, such as holding hope and resignation simultaneously, or moving between guilt, anger, and defiance depending on the context of discussion. This variability is consistent with a constructivist and appraisal-based view of emotion, in which the emotional meaning of the same broad issue can shift with context, social framing, and prior experience. It also has direct methodological consequences: experimental stimuli designed to elicit climate emotions need to specify the relevant appraisal profile, rather than assuming that a general climate-related topic or emotion label is sufficient.

A further observation was that action tendencies differed depending on whether appraisals activated a concrete target for agency. Anger directed at identifiable institutions or decision-makers was described as energising and action-oriented, whereas anger directed at humanity in general was more often linked to paralysis or resignation. Similarly, hope grounded in concrete examples of collective efficacy supported engagement, whereas hope that felt vague or unrealistic did not. These findings are consistent with work emphasising the role of efficacy, agency, and constructive hope in climate engagement (Geiger et al., 2023; Ojala, 2015), and they suggest that the behavioural relevance of climate emotions depends on how responsibility, coping potential, and possible action are appraised.

Study 1 provided an empirical map of climate emotions, including their contexts, appraisal patterns, coping responses, and action tendencies. This map informed the selection of emotion categories and provided material for the development of naturalistic emotional stimuli in Study 2.

7. STUDY 2. ELICITING CLIMATE EMOTIONS

7.1. Rationale

Study 1 provided an empirical account of how climate emotions are experienced, named, and regulated. It showed that climate emotions are context-dependent, appraisal-shaped states linked to different coping responses and action tendencies. These findings had direct methodological implications. To test whether specific climate emotions causally influence PEB, it was first necessary to develop stimuli that could elicit these emotions in a systematic and theoretically controlled way.

The aim of Study 2 was therefore to develop and validate a standardised set of naturalistic text stimuli: the Emotional Climate Change Stories (Zaremba et al., 2024). As argued in the general introduction, short narratives are well suited to appraisal-based emotion induction because they allow causal structure, future consequences, coping possibilities, and normative meaning to be specified more clearly than isolated images. They also offer sufficient standardisation of length, complexity, and presentation time, which is crucial for behavioural and neuroimaging experiments.

The selection of emotion categories for ECCS was guided by two complementary criteria. Firstly, a number of discrete emotions most consistently identified in the literature as relevant for motivating climate action was identified (Brosch, 2021; Kovács et al., 2024; Reser & Bradley, 2017; Schneider et al., 2021; Shipley & van Riper, 2022; Stanley et al., 2021). Second, the selected emotions were expected, on the basis of CPM, to contain appraisal profiles that could support action-oriented tendencies. Study 2 tested whether emotional stories could be used to reliably elicit a single emotion (e.g., anger) without eliciting the remaining emotions (e.g., compassion, guilt).

7.2. Method

7.2.1. Participants

Three independent samples were used to validate the ECCS. Samples 1 and 2 consisted of native speakers of Polish, while Sample 3 consisted of native speakers of Norwegian. This criterion ensured that participants had a solid command of their respective languages, minimising the possibility of inaccuracies in the collected data. Participants also provided demographic information, including gender, age, place of residence, education, parenthood status, occupation, climate activism, and socio-economic status, as well as their beliefs and concerns about climate change (see Table S2 in the Supplementary Materials for full demographic details).

Sample 1. A total of 749 Polish residents were recruited via social media advertisements and the university mailing list. After a data quality check, data from 601 individuals (504 women, 92 men and five non-binary persons) were retained. Depending on the recruitment platform, participants received either no remuneration or student credit points.

Sample 2. A total of 349 Polish residents were recruited by a professional recruitment company using purposive sampling to reach a diverse group of participants whose demographic profile broadly reflected the population of Poland. After a data quality check, data from 307 individuals (164 women, 142 men and one non-binary person) were retained. Participants received remuneration equivalent to €2.

Sample 3. A total of 450 Norwegian residents were recruited by a professional recruitment company using purposive sampling to reach a diverse group of participants whose demographic profile broadly reflected the population of Norway. After a data quality check, data from 346 individuals (181 women and 165 men) were retained. Participants received remuneration equivalent to €0.50.

7.2.2. Procedure

Development of the stories

The stimulus construction was a bottom-up, data-driven process. The ECCS content was inspired by qualitative material collected in Study 1 and in an additional online survey conducted on a large opportunity sample ($n = 523$). In the survey, participants briefly described specific situations in which they had experienced each of the studied emotions. The survey material was reviewed and tagged according to the thematic structure developed during the interview analysis reported in Study 1. From both sources, we identified excerpts in which participants described having experienced five emotion categories of interest: anger, anxiety, compassion, guilt and hope in the context of climate change.

Based on this material, several hundred short stories were generated, representing the most commonly recurring themes (e.g., drought, storm, heatwave, news on social media, politicians, and conversations with family members). From these, 30 coherent and diverse stories were selected for each emotion category, yielding 150 emotionally evocative stories in total. Additionally, 30 neutral stories were developed from a standardised list of affect-related life events (Cohen et al., 2018).

The stories were subsequently professionally translated into Norwegian and English, and underwent proofreading to ensure they were adjusted to the cultural context, avoiding content that might be specific to a particular culture. All stories were designed to have a similar number of characters (Polish: $M = 307.2$, $SD = 44.49$; Norwegian: $M = 295.2$, $SD = 49.35$; English: $M = 304.0$, $SD = 51.65$). Example stories are shown in Table 2, and a full list of stimuli is provided in Supplementary Materials to the original publication (Zaremba et al., 2024).

Table 2. Stories that were found to best represent each emotion category.

Category	Sample story
Anger (ANG)	Lisha is very rich and likes to change her wardrobe frequently. Ever since she has discovered a website with very cheap clothes, she orders 20–30 items a week. Some turn out to be a poor fit, so she throws them straight into the garbage bin. Still, Lisha does not consider this wasteful, because the clothes were ridiculously cheap.
Anxiety (ANX)	Ada studies the oceans. Recently she had to double check her calculations, which indicated that melting Arctic ice may submerge areas inhabited by tens of millions of people. Unfortunately, her calculations turned out to be correct.
Compassion (COM)	It was a hot day when Emilie was on a bus with her seriously ill rabbit, taking it to the vet. The rabbit had trouble breathing, and the poor air conditioning was not able to cool the bus sufficiently. Before she could get to the vet, the rabbit died in its cage. Emilie got out, sat down at an empty bus stop and began to cry.
Guilt (GUI)	By using plastic, we contribute to the growing environmental catastrophe every day. Even if we segregate waste carefully, there is no guarantee that plastic will be recycled. Patches of plastic garbage float on the surface of the oceans, the largest of which is three times the size of France.
Hope (HOP)	Yoshida has discovered a new species of bacteria. The bacteria are able to break down plastic that would otherwise be deposited in landfills. Yoshida's discovery gained so much publicity that he was awarded another research grant. There are reasons to hope that his solution can be implemented on a large scale.
Neutral (NEU)	Monica entered the room, opened the wardrobe and bent down to reach into one of the lower shelves. She took out her brown pants and put them on. Then she opened a drawer in her dresser and took out a belt. She passed it through the belt loops on her pants and fastened the buckle.

Validation of the dataset

The procedures used across all three samples were as closely matched as possible. Participants completed the study remotely, using their own devices, on a purpose-built, secure web application. First, participants provided their informed consent and completed a demographic questionnaire. They were then informed that they would be asked to read and rate their feelings about short stories describing different situations.

Ratings were provided using a slider ranging from 0 to 99, with scale bounds explicitly defined as follows: valence (from *negative emotions*, through *no emotions*, to *positive emotions*); arousal (from *no arousal* to *strong arousal*); and five emotion categories: anger,

anxiety, compassion, guilt and hope (from *not at all* to *to a large extent*). Participants could return to the instruction screen at any time during the task.

The stories presented in a given session were randomly selected from the full pool, with stories that had accumulated fewer ratings assigned a higher probability of selection. Each trial began with the story displayed in full-screen mode. On the following screen, the story remained visible in the upper portion while participants provided their ratings across all seven scales. There was no time limit, but both reading time and rating time were recorded. After completing ratings for 10 stories, participants could choose to continue or finish the task.

7.2.3. Data analysis

The dimensional properties of the ECCS stories were examined by exploring the distribution of valence and arousal ratings across all three samples. To investigate the discrete emotional properties of the stories, we first examined the distribution of mean ratings on each of the five emotion scales. Then, the effects of story category and sample on mean emotion ratings were tested using a multivariate analysis of variance (MANOVA), followed by univariate ANOVAs for each rating scale separately, corrected for multiple comparisons. Because the three samples differed in theoretically relevant ways, sample comparisons were conducted in two planned steps. First, Samples 1 and 2 were compared because they differed in recruitment strategy and participants' motivation to take part in the study: Sample 1 was an opportunity sample, whereas Sample 2 was a purposive sample. Next, Samples 2 and 3 were compared because they came from different countries and involved different language versions of the ECCS: Sample 2 rated the Polish version, whereas Sample 3 rated the Norwegian version. These comparisons were used to examine whether category-relevant emotion ratings were robust across sampling context and across language versions. Post hoc comparisons were conducted to examine whether ratings on story-category-relevant scales differed between the samples.

To identify stories that most purely and specifically represented each emotion category, a classification procedure was applied based on a five-dimensional hypercube model, in which each axis corresponds to one of the rated emotions (Wierzbica et al., 2015, 2022). Each story's position in the hypercube was determined by its mean ratings, and its distance from each of the five emotion corners was calculated using the standard Euclidean distance

formula, averaged across participants. Stories were assigned to an emotion class if their distance to the corresponding corner fell below a defined threshold; they met this criterion for one class only, and the assigned class matched the story's original category label. Threshold values were determined using a genetic algorithm to create emotion classes of equal size.

7.3. Results

General stimuli characteristics

On average, each story was rated by 147.6 participants (min = 141, max = 155), and each participant rated on average 19.93 - 23.41 stories. Mean story presentation time ranged from 6.8 to 11.5 seconds across samples, and mean story evaluation time ranged from 16.4 to 19.5 seconds. A detailed report of the total number of ratings and the number of stories rated per participant for each sample is provided in Supplementary Materials to the original publication (Zaremba et al., 2024). In the following sections, the abbreviations ANG, ANX, COM, GUI, HOP and NEU are used to denote story category (anger, anxiety, compassion, guilt, hope and neutral, respectively), while full terms are used to denote rating scales.

Dimensional characteristics

In line with previous research, we observed a non-linear relationship between valence and arousal ratings (see Figure 4). Three characteristic clusters of stories emerged: stories evoking negative emotions (ANG, ANX, COM and GUI stories), characterised by high arousal and low valence; neutral stories (NEU stories), characterised by low arousal and moderate valence; and stories evoking positive emotions (HOP stories), characterised by high arousal and high valence. Thus, stories rated more extremely in terms of valence - whether more negative or more positive - were also rated higher in terms of arousal. Although the dispersion of ratings along the valence and arousal dimensions was greater in Sample 1 than in Samples 2 and 3, the overall pattern of results was consistent across all three samples.

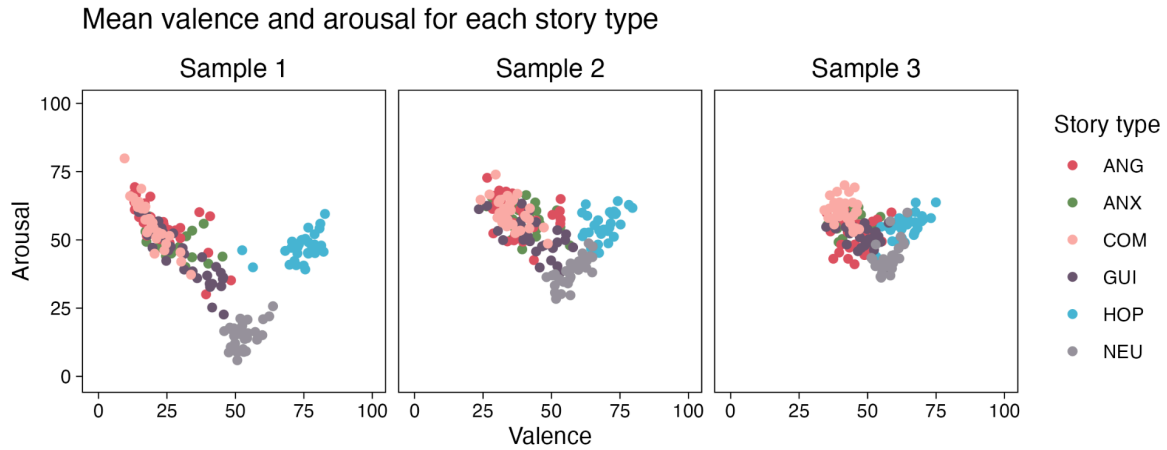


Figure 4. Mean valence and arousal ratings for each story. Individual stories are represented by dots. Colours denote story categories: ANG - anger, ANX - anxiety, COM - compassion, GUI - guilt, HOP - hope, NEU - neutral.

Distinct emotions

To examine the effects of story category and sample on mean ratings of anger, anxiety, compassion, guilt and hope, we first performed a MANOVA with story category as a within-subjects factor and sample as a between-subjects factor. Significant main effects were found for both category, $F(5, 35,050) = 331.05, p < .001$, Pillai's trace = .955, and sample, $F(2, 14,014) = 144.26, p < .001$, Pillai's trace = .187. A significant interaction effect was also observed, $F(10, 35,050) = 36.61, p < .001$, Pillai's trace = .248. To further investigate this interaction, univariate ANOVAs were performed for each rating scale separately, with multiple comparisons corrected, and were followed by post hoc comparisons focusing on story-category-relevant scales. The distribution of mean ratings for each emotion scale and each sample is presented in Figure 5.

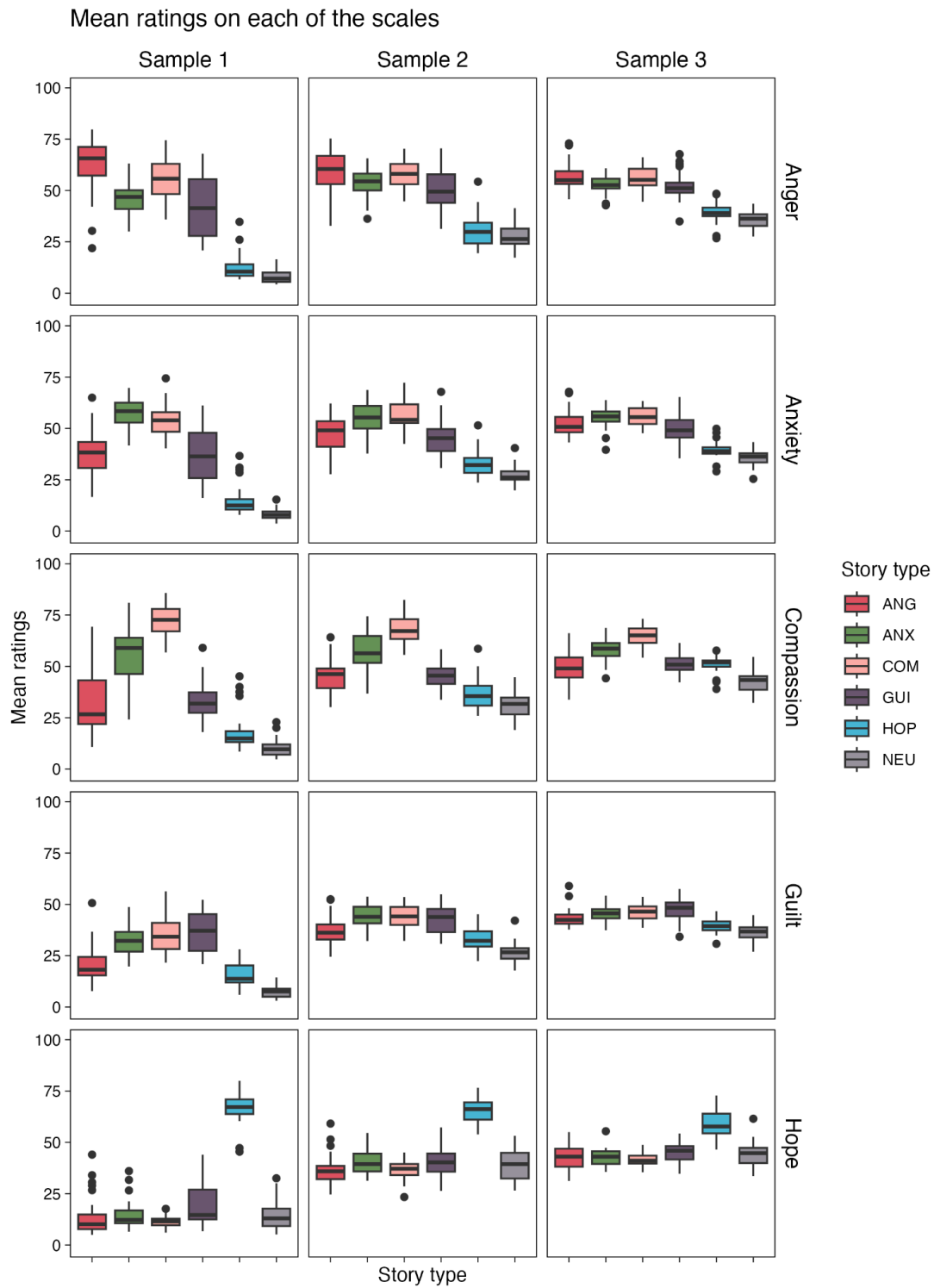


Figure 5. Distribution of mean anger, anxiety, compassion, guilt and hope ratings for each story type. The results are presented separately for each rating scale (rows) and each sample (columns).

Samples 1 and 2. The ANOVAs revealed a significant interaction effect between category and sample for all rating scales: anger, $F(5, 5084) = 18.44, p < .001$, partial $\eta^2 = .02$;

anxiety, $F(5, 5084) = 17.14, p < .001$, partial $\eta^2 = .02$; compassion, $F(5, 5084) = 30.01, p < .001$, partial $\eta^2 = .03$; guilt, $F(5, 5084) = 7.32, p < .001$, partial $\eta^2 = .01$; hope, $F(5, 5084) = 35.87, p < .001$, partial $\eta^2 = .03$. However, post hoc comparisons showed that none of the comparisons between story category and sample were significant for the category relevant scales: ANG stories on the anger scale, $p = .64$; ANX stories on the anxiety scale, $p = .93$; COM stories on the compassion scale, $p = .16$; GUI stories on the guilt scale, $p = .07$; HOP stories on the hope scale, $p > .99$. This indicates that participants from the opportunity sample (Sample 1) and the purposive sample (Sample 2) did not differ significantly in how they rated stories of each category on the relevant emotion scales.

Samples 2 and 3. The ANOVAs similarly revealed a significant interaction effect between category and sample for almost all rating scales: anger, $F(5, 3611) = 8.99, p < .001$, partial $\eta^2 = .01$; anxiety, $F(5, 3611) = 4.09, p = .015$, partial $\eta^2 = .01$; compassion, $F(5, 3611) = 16.28, p < .001$, partial $\eta^2 = .02$; guilt, $F(5, 3611) = 2.15, p = .84$, partial $\eta^2 < .01$; hope, $F(5, 3611) = 5.97, p < .001$, partial $\eta^2 = .01$. Post hoc comparisons again showed no significant interactions between story category and sample for any of the category relevant scales: ANG stories on the anger scale, $p > .99$; ANX stories on the anxiety scale, $p > .99$; COM stories on the compassion scale, $p = .86$; GUI stories on the guilt scale, $p = .33$; HOP stories on the hope scale, $p = .19$. This indicates that participants from Poland (Sample 2) and Norway (Sample 3) did not differ significantly in how they rated stories of each category on the relevant emotion scales.

Specificity of elicited emotions

Given that realistic personal stories about climate change were expected to evoke a range of emotions simultaneously, we applied a classification procedure to identify stories that most specifically and purely represented each emotion category. A range of threshold values was tested by simultaneously increasing the threshold for all classes from 0 to 140, the minimum and maximum possible distances between the hypercube's corners, respectively, and examining how class sizes changed as a result. This exploration revealed that stories were most readily classified into the neutral class, followed by the hope, anger and compassion classes. Almost no stories were classified into the anxiety class, and none were assigned to the guilt class. Based on these findings, threshold values were determined

using a genetic algorithm to create NEU, HOP, ANG, and COM classes of equal size, each containing 9 stories. The resulting distribution of classified stories is presented in Figure 6.

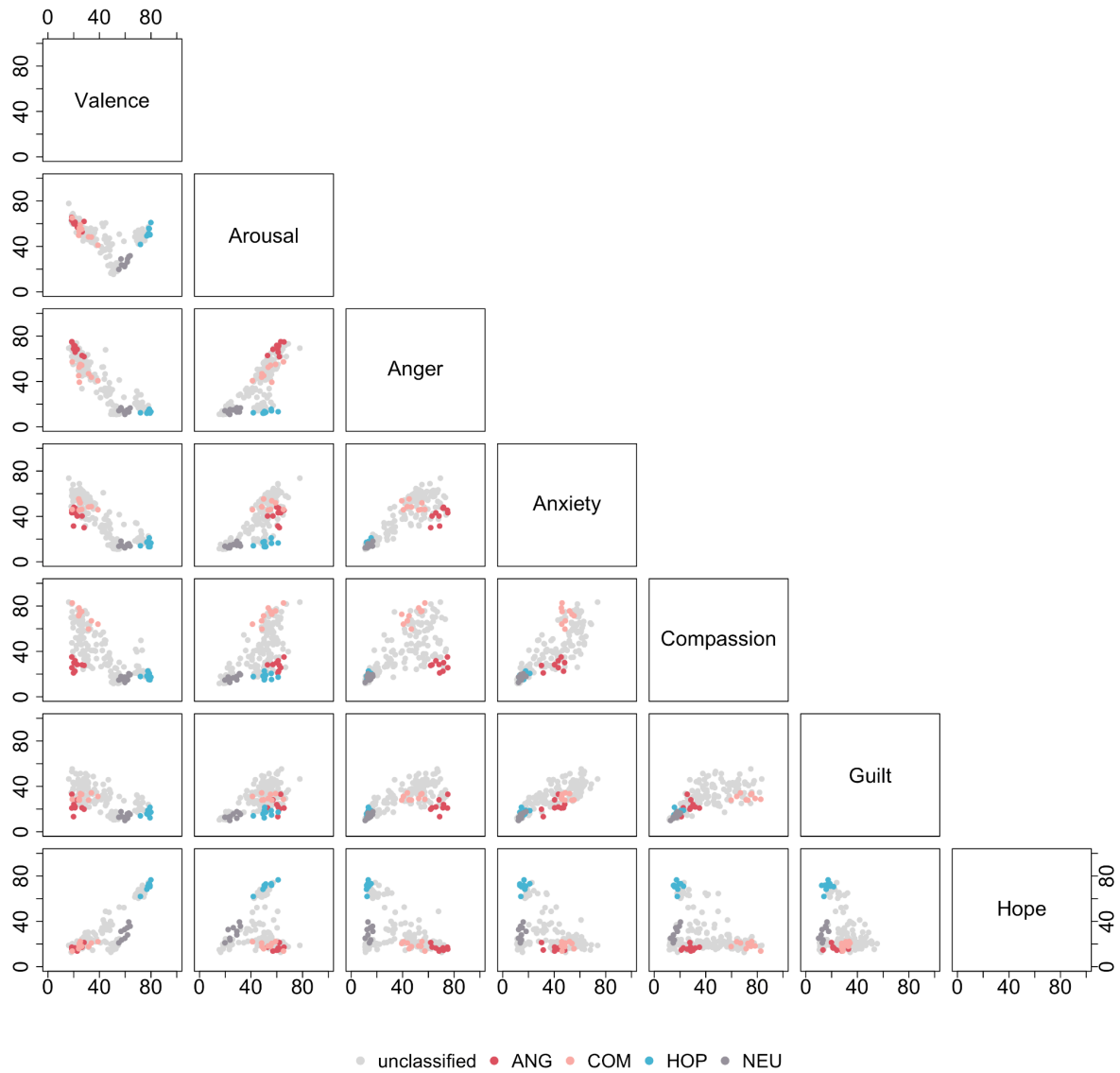


Figure 6. Distribution of story ratings for ANG, COM, HOP and NEU classes identified with the classification algorithm. Rows and columns represent different rating scales: valence, arousal, anger, anxiety, compassion, guilt, and hope. Each subplot shows the distribution of the ECCS stories in the domain of two rating scales. For instance, the top-left corner shows the distribution of stories across valence (horizontal axis) and arousal (vertical axis). Each dot represents one of 180 stories, with colours denoting different classes identified with the classification algorithm: ANG - anger, COM - compassion, HOP - hope, NEU - neutral. Unclassified stories are marked in light grey for visualisation purposes.

7.4. Discussion

Validation conducted in three independent samples confirmed that ECCS stories evoked the intended emotional responses and showed the expected dimensional structure. Hopeful stories were positively valenced and arousing, neutral stories were low in arousal and valence, and negatively valenced stories (anger, anxiety, compassion, guilt) were highly arousing. These patterns were consistent across samples that differed in recruitment strategy, demographic profile, and cultural context.

A classification method (Wierzba et al., 2022) identified subsets of stories that selectively represented each emotion category. Stimuli that evoked anger, compassion and hope were found to be most specific and therefore most suitable for use in the subsequent experimental studies. By contrast, anxiety and guilt stories tended to elicit more mixed emotional responses. Anxiety stories received high ratings not only on the anxiety scale, but also on compassion, anger, and guilt scales, which is consistent with previous findings showing that climate anxiety often co-occurs with other climate emotions (Marczak, Winkowska, et al., 2023; Zaremba et al., 2022). Evoking strong and specific guilt proved particularly challenging. GUI stories were associated with the lowest overall emotional intensity and the least specific emotional response across all categories. This may reflect the fact that most ECCS stories were written in third-person narratives, which may have reduced identification with the protagonist and, in turn, limited the experience of self-relevant guilt. Additionally, people tend to resist emotional appeals that threaten their self-esteem or sense of moral integrity (Ma & Hmielowski, 2022) and may employ coping strategies such as disidentifying with the story's character or minimising the moral significance of climate-unfriendly actions in order to preserve a positive self-image (Caillaud et al., 2016). Similarly, climate anxiety may activate maladaptive emotion-focused coping strategies, such as denial or de-emphasising the perceived threat, which could attenuate the specificity of anxiety ratings (Haltinner & Sarathchandra, 2018; Heeren & Clayton, 2026; Ojala & Chen, 2024).

These findings support the appraisal-based interpretation developed in Study 1. Realistic climate narratives can elicit distinct emotions, but they also reveal overlap between appraisal profiles. This overlap reflects the structure of climate emotions, which often combine threat, responsibility, harm to others, coping difficulty, and moral evaluation. For

experimental use, however, this means that stimuli should be selected according to both their intended category and their empirical specificity.

Linking forward, Study 2 provided validated stimuli with both dimensional and discrete emotion properties, suitable for use in controlled experimental settings. The results justified the selection of anger, compassion, and hope for Study 3, where ECCS stories were used to test whether induced climate emotions influence consequential PEB.

8. STUDY 3. IMPACT OF EMOTION ON CLIMATE ACTION

8.1. Rationale

Study 2 produced a validated set of climate-related emotional stories and identified anger, compassion, and hope as the stimulus categories that evoked the most specific emotional responses. These three categories were therefore selected for the first experiment to test whether induced climate emotions can increase PEB. Each of these emotions has been identified as relevant to climate action, but they differ in their appraisal profiles and expected action tendencies (Brosch & Steg, 2021; Geiger et al., 2023; Gregersen et al., 2025; Landmann & Hess, 2017; Pfattheicher et al., 2016).

The aim of Study 3 was to test whether exposure to climate-emotion stories increased consequential PEB relative to neutral stories, and whether anger, compassion, and hope differed in their behavioural effects. Based on their appraisal profiles, anger was expected to increase preference for punitive or corrective action directed at responsible agents, compassion was expected to increase preference for helping those affected by climate change, and hope was expected to increase preference for supporting promising solutions. In addition to these emotion-specific hypotheses, the study examined whether broader psychological, contextual, and demographic factors explained variation in PEB. The analysis plan was preregistered (Zaremba et al., 2023).

By combining validated emotion induction with consequential behavioural measures, Study 3 tested whether climate emotions can influence concrete action rather than only self-reported intentions. Its findings also provided the basis for the next stage of the programme. In particular, the study tested whether the ECCS manipulation was effective at the self-report level, whether it translated into behaviour, and which design features should be refined in the subsequent neuroimaging study.

On this basis, the following hypotheses were tested:

Effects of climate emotion induction on PEB

H1. Exposure to emotional climate stories, irrespective of emotion category, was expected to increase PEB relative to neutral stories.

H2. The level of engagement in PEB was expected to differ depending on the type of induced climate emotion: anger, compassion, or hope.

Emotion-specific action tendencies

H3. Induced climate emotions were expected to increase emotion-specific action tendencies. Specifically, anger was expected to increase preference for punitive or corrective action directed at responsible agents, compassion was expected to increase preference for helping those affected by climate change, and hope was expected to increase preference for supporting promising solutions.

Psychological, contextual, and demographic predictors of PEB

H4. PEB was expected to be associated with broader psychological, contextual, and demographic factors, including valence, arousal, belief in climate change, climate change concern, perceived efficacy, psychological distance, willingness to sacrifice for the environment, and demographic characteristics.

8.2. Method

8.2.1. Participants

The sample size was based on the preregistration. Participants were recruited in Poland (N = 1029) and Norway (N = 1010) among adult native Polish speakers and native Norwegian speakers, respectively. The demographic profile (gender, age, and education level) broadly reflected the Polish and Norwegian populations (see Tables S3 and S4 in the Supplementary Materials). Additionally, a similar number of participants with low, moderate, and high levels of climate change concern were selected. The study was conducted online, and volunteers were recruited by an external company via mass mailing,

targeting a broad range of respondents. Participants received remuneration equivalent to 20 PLN (~4,5 EUR) and 200 NOK (~17 EUR), respectively.

8.2.2. Procedure

Questionnaire measures

Participants completed several questionnaires measuring variables relevant to pro-environmental intentions and behaviors: level of climate change belief and concern, personal and collective climate action efficacy (Chu & Yang, 2020), psychological distance to climate change (van Valkengoed et al., 2021), willingness to sacrifice for the environment (Davis et al., 2011), as well as a demographic survey (gender, age, place of residence, education level, socio-economic status, parenthood status).

ECCS reading

ECCS stories that elicited the target emotions most strongly were selected based on the ratings collected in Study 2. Depending on the assignment to one of the 4 conditions, stories were meant to evoke anger (ANG), compassion (COM), or hope (HOP), or to maintain a neutral state (NEU). Additionally, the story content was checked against appraisal-theoretic criteria to ensure alignment with the appraisal patterns summarised in Table 1. The mean length of stories in Poland was 294.6 characters (SD = 54.39), while in Norway, it was 281.3 characters (SD = 59.88). In each condition, participants read 9 stories at their own pace. Ratings of valence, arousal, and each of the investigated discrete emotions were collected as manipulation checks.

Donation intention and aim preference

Donation intention was measured with a single question ('Would you make a donation to a climate change organisation?'; answer provided on a 4-point scale from "Definitely no" to "Definitely yes"). Participants could also indicate their preferred donation aim by choosing one of the following options: fighting against corporations and policies that exacerbate climate change, aiding those affected by climate change, investing in solutions to mitigate climate change, or none of the above.

Work for the Environmental Protection Task

The Work for Environmental Protection Task (WEPT; (Lange & Dewitte, 2021)) is a multi-trial procedure that measures cognitive and time effort invested into environmental protection. In each of the 15 trials, participants could voluntarily complete a mundane number identification task (Figure 7). Each accurate completion of the task generated a small donation to WWF (0.5 PLN in Poland or 4 NOK in Norway; a maximum of 7.5 PLN or 60 NOK). To encourage participants to engage in the task, they were informed that donations would depend on accuracy (the trial was considered complete if at least 90% of the numbers were identified correctly). Earlier validation studies showed that people are sensitive to the environmental consequences of their choices in WEPT, with sensitivity modulated by the amount of effort and the size of the environmental benefit (Lange & Dewitte, 2023).

Identify all those stimuli with an even first digit and an odd second digit. For example, you should click on "25", because the first digit (2) is even and the second digit is odd (5).

47	72	39	59	15	84	88	82	44	57
☒	☐	☐	☐	☐	☐	☐	☐	☐	☐
59	38	68	46	32	81	67	71	69	84
☐	☐	☐	☐	☐	☒	☒	☐	☒	☐
35	48	25	78	73	87	18	87	74	89
☐	☐	☒	☐	☐	☒	☐	☐	☐	☐
32	75	28	82	29	82	62	51	74	66
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

The next page will contain **40 numbers** and we will donate **0.20 Euro** for the protection of the rainforest if you complete this page.

If you decide to complete this page, please do so thoroughly because we can only count pages that are at least 90% correct. We will not give you feedback, so please check whether your answers are correct before proceeding to the next page.

Do you want to complete this page?

yes no

☒ ☐

Figure 7. Overview of the Work for Environmental Protection Task. Reprinted from F. Lange and S. Dewitte, 2022, doi.org/10.3758/s13428-021-01617-2. Copyright 2021 by The Psychonomic Society, Inc. Reprinted with permission.

Donation task

A direct monetary donation from the study remuneration was used as a complementary measure of PEB (Clements et al., 2015). At the end of the experiment, participants were given the opportunity to donate part of their remuneration to WWF (a maximum of 20 PLN in Poland and 200 NOK in Norway). Unlike WEPT, in which participants invested time and effort but could not retain the donated amount for themselves, the donation task involved a direct trade-off between personal and environmental benefit.

Study design

A purpose-built, secure web application was used to collect the data. Each participant was dynamically assigned to one of the four experimental conditions with the smallest number of observations at the given moment. The participants first read the description of the study's aims and provided informed consent. Next, they completed a set of questionnaires and a demographic survey. Then, participants underwent emotion manipulation with ECCS stories. Immediately afterwards, participants were asked about their donation intentions and preferred donation aims. Finally, they completed two PEB tasks: WEPT and donation. The entire procedure took approximately 20 minutes; see Figure 8.

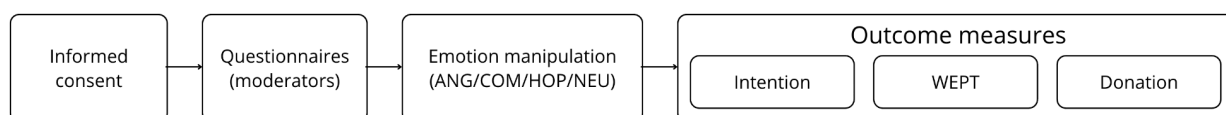


Figure 8. Overview of the experimental procedure.

8.2.8. Data analysis

Data analysis was conducted using R statistical software (R Core Team, 2023). Complete datasets and analysis scripts are publicly available on github.com/nencki-lobi/PEB.

Data quality was evaluated by cross-referencing participants' responses regarding sex, age, and level of climate change concern with their answers to the same items in the screening survey administered at recruitment. Participants whose responses were inconsistent across the two time points were excluded (in Poland: 6 due to inconsistent sex reporting, 22 due to inconsistent age, and 8 due to inconsistent level of climate change concern; in Norway:

28 due to inconsistent sex reporting, 13 due to inconsistent age, and 27 due to inconsistent level of climate change concern). The preregistered hypotheses were tested as follows:

H1. Relative to the neutral condition, participants exposed to any emotional stories (pooled across conditions) were expected to show higher PEB, operationalised as (H1a) greater effort on the WEPT task and (H1b) larger donations. Both hypotheses were tested using Welch two-sample t-tests, conducted separately within each country sample.

H2. Relative to the neutral condition, exposure to distinct emotional story types was expected to produce different levels of PEB, which were examined using the following planned contrasts: ANGER vs NEUTRAL, COMPASSION vs NEUTRAL, and HOPE vs NEUTRAL. Pairwise comparisons among the three emotion conditions (ANGER, COMPASSION, HOPE) were also conducted. These effects were examined separately for (H2a) WEPT effort and (H2b) donations within each country sample using one-way analyses of variance (ANOVAs).

H3. Donation aim preferences were expected to vary as a function of the induced emotion condition: (H3a) anger was predicted to increase preference for punitive or corrective aims, (H3b) compassion was predicted to increase preference for aims focused on helping those affected, and (H3c) hope was predicted to increase preference for solution-oriented aims. These hypotheses were tested using chi-square tests of independence (aim $\times$ condition), conducted separately within each country sample.

H4. Beyond the experimental manipulation, individual difference variables (including climate change concern, efficacy beliefs, psychological distance, willingness to sacrifice, and demographic characteristics) were expected to moderate PEB outcomes. These effects were examined using multiple regression models, estimated separately within each country sample.

To characterise the sensitivity of the final samples, sensitivity analyses were conducted for the main preregistered tests, assuming two-sided $\alpha = .05$ and 80% power. While a composite pro-environmental behaviour score (cPEB; a weighted average of completed WEPT tasks and donation amount) was calculated as per preregistration, it did not provide additional insights beyond the individual tasks and is therefore not reported here to

maintain clarity. Results for cPEB can be found in the Supplementary Materials to the original publication (Zaremba et al., 2026).

8.3. Results

Descriptive statistics

Following data quality control, the final samples included 1,029 participants in Poland and 1,010 in Norway. Participants in Poland spent more time reading the stories ($M = 15.11$, $Mdn = 11.88$, $SD = 35.41$ seconds) than participants in Norway ($M = 10.18$, $Mdn = 8.54$, $SD = 12.47$ seconds), with considerably greater variability in reading times observed in the Polish sample.

The effectiveness of the emotion manipulation was evaluated by examining story ratings both within and between experimental groups; descriptive statistics are presented in Table 3. Consistent with expectations, participants assigned to the HOPE condition reported a more positively valenced state relative to those in other conditions. Reported arousal was also elevated among participants exposed to emotional stories compared to those who read neutral stories. Moreover, each experimental group assigned the highest ratings on the scale corresponding to the emotion targeted by their condition: the ANGER group on the anger scale, the COMPASSION group on the compassion scale, and the HOPE group on the hope scale. NEU stories were rated as slightly positive. COM stories were additionally characterised by elevated anger ratings. This pattern of results was observed in both the Polish and Norwegian samples, indicating cross-cultural consistency of the manipulation effects; inferential manipulation check results are reported in Supplementary Materials to the original publication (Zaremba et al., 2026).

Table 3. Means and standard deviations of story ratings across experimental conditions in Poland and Norway. Bolded text shows ratings on matched emotion scales.

	Poland: M (SD)				Norway: M (SD)			
Rating scale	NEUTRAL N = 260	ANGER N = 257	COMPASSION N = 261	HOPE N = 251	NEUTRAL N = 244	ANGER N = 256	COMPASSION N = 255	HOPE N = 255
Valence	70.11 (20.53)	20.58 (23.13)	20.54 (22.60)	81.66 (19.74)	62.96 (20.85)	31.02 (26.50)	32.38 (26.97)	73.50 (21.17)
Arousal	38.81 (25.18)	63.17 (23.98)	69.74 (22.75)	60.78 (24.93)	44.81 (26.03)	53.40 (24.76)	63.85 (24.14)	58.13 (24.87)
Anger	11.52 (20.45)	70.86 (25.35)	63.86 (27.60)	14.47 (22.53)	23.62 (26.65)	62.64 (24.15)	54.76 (26.70)	24.89 (26.81)
Compassion	25.06 (25.68)	40.17 (29.45)	82.10 (21.91)	29.12 (28.52)	48.53 (26.99)	38.25 (28.24)	72.15 (21.99)	57.79 (27.11)
Hope	48.77 (31.19)	21.12 (25.00)	31.99 (27.00)	76.38 (24.25)	48.07 (26.45)	32.25 (25.18)	36.20 (24.84)	68.51 (24.19)

Participants correctly completed 54% of all possible WEPT trials in Poland and 38% in Norway. Trials falling below the 90% accuracy threshold accounted for 3.5% of all attempts in Poland and 2% in Norway. On average, participants in Poland completed 8.16 WEPT trials (SD = 5.72, Mdn = 7), generating a mean donation of 4.08 PLN (~0.95 EUR), equivalent to 54.4% of the maximum possible amount (7.5 PLN). In Norway, participants completed an average of 5.83 trials (SD = 5.41, Mdn = 4), generating a mean donation of 23.32 NOK (~2.04 EUR), equivalent to 38.9% of the maximum (60 NOK). In the direct donation task, participants could allocate a portion of their study remuneration to WWF, up to 20 PLN (~4.5 EUR) in Poland and 200 NOK (~17 EUR) in Norway. Mean donations amounted to 3.60 PLN (~0.84 EUR; SD = 4.99, Mdn = 1) in Poland, corresponding to 18% of the total remuneration, and 63.57 NOK (~5.55 EUR; SD = 79.01, Mdn = 10) in Norway, corresponding to 31.8% of total remuneration. The two behavioural measures of PEB were only weakly correlated ($r = .14$ in Poland; $r = .16$ in Norway).

Registered analyses

The first hypothesis predicted that exposure to any climate-related emotion would increase PEB relative to the neutral condition. For the t-tests comparing the neutral condition with the pooled emotional conditions, the minimum detectable effect corresponded to Cohen's $d = .201$ in Poland and $d = .206$ in Norway. Welch two-sample t-tests revealed no significant differences between participants exposed to emotional and neutral stories in either country. In Poland, non-significant results were obtained for both WEPT performance ($t(452.58) = -1.53$, $p = .127$, $d = -.14$, 95% CI $[-.33, .04]$) and donation amount ($t(449.99) = .91$, $p = .363$, $d = .09$, 95% CI $[-.10, .27]$). The same pattern was observed in Norway, where neither WEPT performance ($t(394.65) = 1.29$, $p = .199$, $d = .13$, 95% CI $[-.07, .33]$) nor donation amount ($t(433.35) = -.68$, $p = .497$, $d = -.07$, 95% CI $[-.25, .12]$) differed significantly between groups. Effect sizes were negligible in both samples.

The second hypothesis predicted that PEB would vary across the conditions. For the four-group ANOVAs, the minimum detectable effect sizes were Cohen's $f = .103$ in Poland and $f = .104$ in Norway, corresponding to $\eta^2 \approx .011$ in both samples. The ANOVA results did not support this hypothesis. In Poland, no significant effect of condition was found for WEPT performance ($F(3, 1025) = .87$, $p = .455$, $\eta^2 = .003$) or donation amount ($F(3, 1025) = .92$, $p = .429$, $\eta^2 = .003$). Similarly, in Norway, condition did not significantly predict WEPT performance ($F(3, 1006) = 1.09$, $p = .353$, $\eta^2 = .003$) or donation amount ($F(3, 1006) = 1.31$, $p = .270$, $\eta^2 = .004$). Effect sizes were negligible in both samples.

The third hypothesis concerned whether the emotion induction increased action tendencies specific to each induced emotion: anger was predicted to increase preference for punitive or corrective aims, compassion for aims oriented towards helping those affected, and hope for solution-focused aims. For the chi-square tests of donation aim preference, the minimum detectable associations corresponded to Cohen's $w = .129$ in Poland and $w = .134$ in Norway, equivalent to Cramér's $V = .074$ and $V = .077$, respectively. The observed donation aim $\times$ emotion category frequencies were compared with the expected frequencies under the assumption that donation aim preference was independent of emotion category. Chi-square tests did not yield significant results in either the Polish or Norwegian sample (Poland: $\chi^2(9) = 16.58$, $p = .056$, Cramér's $V = .05$; Norway: $\chi^2(9) = 9.56$, $p = .387$, Cramér's $V = .01$).

To examine whether individual difference variables identified in prior literature were associated with PEB outcomes, separate linear regression models were estimated for each country. Each model included experimental condition, post-manipulation valence and arousal ratings, belief in climate change (BCC), climate change concern (CCC), personal and collective action efficacy (PCAE), psychological distance (PD), willingness to sacrifice for the environment (WTS), sex, age, place of residence (RES), education level (EDU), parenthood status, and socioeconomic status (SES). Multicollinearity was low across all preregistered main-effect models, indicating that the inclusion of multiple predictors was unlikely to have substantially inflated standard errors.

WEPT (Poland). The model accounted for a small proportion of variance in WEPT performance ($R^2 = .063$, adj. $R^2 = .038$; $F(27, 997) = 2.49$, $p < .001$). Experimental condition was not a significant predictor (all condition contrasts ns). Age emerged as a positive predictor of WEPT performance ($b = .049$, $p < .001$).

Donations (Poland). The model accounted for a small proportion of variance in donation amount ($R^2 = .071$, adj. $R^2 = .046$; $F(27, 997) = 2.84$, $p < .001$). The experimental condition was again non-significant (all conditions contrasts ns). Higher WTS, older age, and higher education level were each associated with larger donations (WTS: $b = .070$, $p = .018$; age: $b = .054$, $p < .001$; education: relative to the primary education reference category, secondary, vocational, and university/college levels were all significant at $ps \leq .037$).

WEPT (Norway). The model accounted for a moderate proportion of variance in WEPT performance ($R^2 = .178$, adj. $R^2 = .155$; $F(28, 969) = 7.51$, $p < .001$). The experimental condition was not a consistent predictor: relative to the NEUTRAL group, the ANGER condition showed a small negative association with WEPT performance at the threshold of significance ($b = -1.007$, $p = .050$), while COMPASSION and HOPE conditions were not significant ($ps \geq .19$). Age was again a strong positive predictor ($b = .117$, $p < .001$). Relative to the reference BCC category, endorsing the view that climate change is 'rather not happening' was associated with lower WEPT performance ($b = -2.206$, $p = .002$), as was higher psychological distance ($b = -.178$, $p = .029$). Reporting financial difficulty on present income was associated with higher WEPT performance ($b = 1.287$, $p = .005$).

Donations (Norway). The model accounted for a moderate proportion of variance in donation amount ($R^2 = .149$, adj. $R^2 = .124$; $F(28, 969) = 6.04$, $p < .001$). The experimental condition was not a significant predictor. Age again emerged as a strong positive predictor ($b = .950$, $p < .001$). Higher levels of CCC (levels 4 and 5), lower WTS, male sex, and lower SES were each associated with smaller donations (CCC: $ps < .012$; WTS: $b = 1.232$, $p = .002$; sex: $b = -13.167$, $p = .007$; SES: $ps < .021$).

Taken together, the experimental condition was not a robust predictor of PEB outcomes in the regression models across either country, while age emerged as the most consistent positive predictor. This pattern is consistent with the descriptive data, in which observed means for WEPT performance and donation amount were closely comparable across the conditions in both samples. Condition-level descriptive statistics are presented in Table 4, and full regression results are presented in the original publication (Zaremba et al., 2026).

Table 4. Descriptive statistics for key PEB outcomes by experimental condition in Poland and Norway. Values are observed means with standard deviations in parentheses.

Group	Poland: M (SD)		Norway: M (SD)	
	WEPT	Donations	WEPT	Donations
NEUTRAL	7.69 (5.65)	3.85 (4.96)	6.23 (5.59)	60.68 (75.15)
ANGER	8.27 (5.71)	3.62 (5.21)	5.38 (5.19)	70.01 (82.87)
COMPASSION	8.47 (5.71)	3.76 (5.46)	5.80 (5.27)	66.19 (79.23)
HOPE	8.20 (5.81)	3.17 (4.22)	5.95 (5.58)	57.28 (78.31)

The addition of preregistered condition-by-moderator interaction terms did not improve model fit relative to the main-effects models ($F(73, 896) = 1.11$, $p = .256$), with no improvement observed for either outcome in Poland (WEPT: $p = .441$; donations: $p = .435$) or Norway (WEPT: $p = .777$; donations: $p = .256$). Given that the main-effects models themselves provided little evidence for condition effects, and that all reported p-values are uncorrected, the condition-by-predictor interaction results were not treated as a basis for substantive conclusions regarding moderation and are not reported in the thesis. These

analyses are available in the Supplementary Materials to the original publication (Zaremba et al., 2023).

8.4. Discussion

Study 3 investigated whether induced climate anger, compassion, and hope increased PEB relative to a neutral condition, and whether these distinct emotions produced different action tendencies. Despite effective emotion induction at the self-report level, no significant differences in WEPT performance, donation amounts, or donation aim preferences were observed between emotional and neutral conditions in either the Polish or the Norwegian sample. Age was the only consistent predictor of PEB across both countries and both outcome measures. Effect sizes were negligible throughout.

The convergence of null results across two culturally and contextually distinct national samples suggests that brief, text-based emotion induction does not reliably increase PEB in the paradigm employed here. These results invite deeper investigation of the boundary conditions, because the broader literature links climate emotions with intentions, policy support, and engagement (Brosch, 2021; Carrus et al., 2021; Shipley & van Riper, 2022). Evidence for the effectiveness of brief interventions is mixed: some studies report that even short online interventions can impact climate advocacy behaviours (Goldwert et al., 2026; Vlasceanu et al., 2024), but most studies report modest effects, with outcomes depending on the study context and design (Bergquist et al., 2023; Geiger et al., 2023; Nisa et al., 2019). Several methodological factors are discussed as the potential reason why the self-reported emotional response was not sufficient to motivate measurable change in PEB.

First, the emotional responses elicited by the stories were not fully distinct at the descriptive level. The co-elicitation was most evident for COM stories, where compassion ratings were highest as intended, but anger ratings were also notably elevated. This pattern is theoretically meaningful because concern for victims can naturally co-occur with appraisals of harm, injustice, and responsibility. Even though co-elicitation may have reduced between-condition differences and weakened emotion-specific behavioural effects it is unlikely to fully explain the null effects. Had insufficient emotion specificity been the primary mechanism, emotional stories, as a broader category, would still be expected to produce higher PEB than neutral stories. This difference was not observed (H1).

Second, the elicited emotions may not have been sufficiently intense or sustained to impact behaviour choices in a single, online experimental session. Participants read the stories once, at their own pace, and then completed behavioural tasks that imposed their own demands and incentives. In this context, the induced state may have weakened over time. This interpretation is consistent with evidence that brief interventions can produce small and heterogeneous effects, depending on intervention content, timing, and outcome type (Bergquist et al., 2023; Nisa et al., 2019).

Third, the behavioural measures used in Study 3 captured only selected types of PEB. Although WEPT and the donation task are consequential and widely used, both have notable limitations. In WEPT, each trial is identical in terms of required time and effort, and each produces the same environmental benefit. This design may obscure more nuanced differences in approach motivation as a function of these parameters (Lange & Dewitte, 2023). The donation task, in turn, provides only a single behavioural measurement per participant.

Despite these limitations, Study 3 had several strengths: it was preregistered, used large samples in two countries, included manipulation checks, and measured consequential behaviour rather than only intentions. The convergence of null effects across samples and behavioural outcomes therefore provides informative evidence that short, incidental climate emotion inductions may have limited effects on immediate PEB.

The findings and methodological limitations directly informed Study 4. To reduce overlap between emotional categories, the subsequent neuroimaging study focused on anger and hope, omitting compassion. The experimental setting was also moved to the laboratory, story presentation was more tightly controlled, and a different outcome measure of PEB was employed. This trial-based decision task was better matched to the technical requirements of the neuroimaging setting and offered greater trial-to-trial variability, increasing the sensitivity to within-participant variation in climate-relevant choices.

9. STUDY 4. NEUROIMAGING CLIMATE EMOTIONS AND PEB

9.1. Rationale

Study 3 showed that ECCS stories successfully elicited the intended emotional responses at the self-report level, but did not reliably increase PEB. This finding left open an important mechanistic question: whether the stories nevertheless engaged appraisal-related processes during emotion induction, and whether these processes could be observed at the level of brain activity. Study 4 therefore investigated brain activity associated with climate emotions and climate-relevant decisions. The study focused on climate anger and climate hope. These two emotions were retained because they were theoretically central to the thesis, were among the categories most specifically elicited in Study 2, and formed a clear contrast in valence and appraisal structure. Compassion was not included in the fMRI design because Study 2 and Study 3 indicated stronger overlap with anger, which could reduce interpretability in a between-group neuroimaging design.

The study combined three complementary components. First, the Reading and Rating Emotional Stories task (RRES) was used to examine subjective and brain responses to anger-evoking, hope-evoking, and neutral stories. This was used to test whether appraisal-informed climate narratives engage brain regions associated with emotion processing. Second, the Carbon Emission Task (CET) was used to examine climate-relevant decision-making in a consequential, trial-based behavioural task adapted for fMRI. This made it possible to test brain activity related to decisions involving a trade-off between personal financial gain and climate benefit. Third, baseline climate emotions were measured with the Inventory of Climate Emotions (ICE; Marczak et al., 2023) before the manipulation, allowing the study to distinguish short-term induced emotional states from more stable emotional dispositions toward climate change.

The overarching aim of Study 4 was therefore to examine whether climate anger and climate hope are associated with appraisal-related brain activity during story reading, whether climate-relevant decisions engage valuation and control-related brain systems, and whether induced or baseline climate emotions predict PEB and its brain correlates. On this

basis, hypotheses were formulated to examine the following patterns of behaviour and brain activity:

Climate emotions - behaviour and brain activity

H1. Emotional climate stimuli were expected to differ from neutral stimuli in subjective ratings of valence and arousal.

H2. At the level of brain activity, emotional climate stimuli were expected to show stronger activation than neutral stimuli in brain regions associated with relevant appraisal processes, consistent with a componential view of emotion.

H3. Preferential engagement of regions involved in evaluating negative valence was expected in response to climate anger-evoking stimuli.

H4. Preferential engagement of regions supporting positive valence processing was expected in response to climate hope-evoking stimuli.

Climate-relevant decisions - behaviour and brain activity

H5. Climate-related decision-making was expected to engage brain regions associated with valuation and decision-making processes.

H6. Distinct patterns of brain activity were expected for pro-environmental versus self-interest choices, with increased activation in the lateral prefrontal cortex (DLPFC) predicted for pro-environmental behaviour.

Effects of emotion manipulation on climate-relevant behaviour and brain activity

H7. Emotional climate stimuli were expected to increase pro-environmental behaviour compared with neutral stimuli.

H8. Emotional climate stimuli were expected to increase decision-related brain activity in predefined ROIs compared with neutral stimuli.

H9. Emotional climate stimuli were expected to modulate the difference between brain activity during pro-environmental and self-interest choices, within predefined ROIs.

Baseline climate emotions and PEB

H10. Self-reported climate emotions measured before the experimental manipulation were expected to predict pro-environmental choices.

H11. Individual differences in self-reported climate emotions were expected to modulate the difference between brain activity during pro-environmental and self-interest choices.

9.2. Method

All procedures complied with the Declaration of Helsinki and were approved by the SWPS University Ethical Review Board (2023-167). The study protocol, materials, and acquisition procedures used in this dissertation were documented in detail in a separate publication (Zaremba, Kossowski, et al., 2025). Moreover, the data collected in this study were published as the CLIMATE BRAIN dataset. The dataset is openly available on OpenNeuro (ds005460) and is organised according to the Brain Imaging Data Structure (BIDS), a standardised format for arranging neuroimaging files and accompanying metadata. It includes raw and preprocessed neuroimaging data alongside participant-level and task event files; behavioural data are additionally available on the Open Science Framework. The present Method section focuses on elements directly relevant to the current research questions.

9.2.1. Participants

The sample consisted of N=160 healthy young adults with moderate climate change concern recruited in Poland. Detailed sample characteristics, recruitment, inclusion criteria, demographic and questionnaire variables are reported in the dataset descriptor (Zaremba, Kossowski, et al., 2025). Participants provided written informed consent using an extended form based on the Open Brain Consent template (Bannier et al., 2021). Full demographic data are presented in Table S5 in the Supplementary Materials.

9.2.2. Procedure

Questionnaire measures

Participants completed a set of questionnaire measures of Personal and Collective Action Efficacy (Chu & Yang, 2020), Psychological Distance to Climate Change (van Valkengoed et al., 2021), and Nature Relatedness (Nisbet & Zelenski, 2013). Trait climate emotions were measured with the Inventory of Climate Emotions (Marczak, Wierzbna, et al., 2023).

The full content of the self-report measures is presented in the related publication (Zaremba, Kossowski, et al., 2025).

Reading and Rating Emotional Stories (RRES)

The RRES task was designed to examine brain activity related to distinct climate emotions. While in the MRI scanner, participants read a set of stories selected from ECCS. Each group of participants read different types of stories - either anger-evoking (ANG), hope-evoking (HOP) or neutral stories (NEU). Stories were presented in 3 runs, each consisting of 4 target (TAR) and 4 control (CON) stories. Participants read them and rated their emotional reactions on valence and arousal scales (slider scales) while the brain activity was recorded. An overview of the task is provided in Fig. 9.

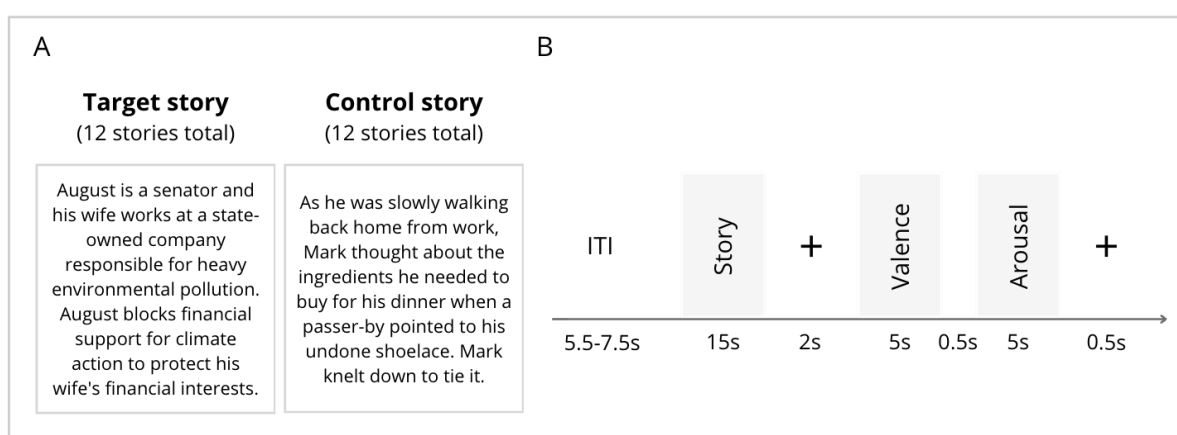


Figure 9. Reading and Rating Emotional Stories (RRES) task overview. (A) Participants read either climate-related stories (ANGER and HOPE) or neutral everyday stories (NEUTRAL). Example target and control stories are shown. (B) Trials began with a story presentation and continued with a rating phase, with jittered intervals between trials.

Carbon Emission Task

The Carbon Emission Task is designed to measure readiness to forgo personal financial gain for the sake of climate change mitigation (Berger & Wyss, 2021). In this task, participants make a series of choices between receiving a monetary bonus and retiring carbon emission certificates. Choosing the climate-friendly option reduces the number of certificates available for purchase in the Emission Trading Scheme. Emissions trading is an effective strategy for limiting carbon emissions (Jung & Song, 2023), making the CET task an ecologically valid way to measure pro-environmental behaviour related to climate

change. In this experiment, the original CET was adjusted to fMRI settings by: (1) simplifying the visual layout of the task; (2) optimizing stimulus duration and inter-trial intervals to improve signal-to-noise ratio; (3) increasing the total number of trials; (4) calibrating the monetary rewards and carbon emission values; and (5) introducing dummy trials to account for motor responses (e.g., “choose the option on the left/right”). An overview of the task is provided in Fig. 10.

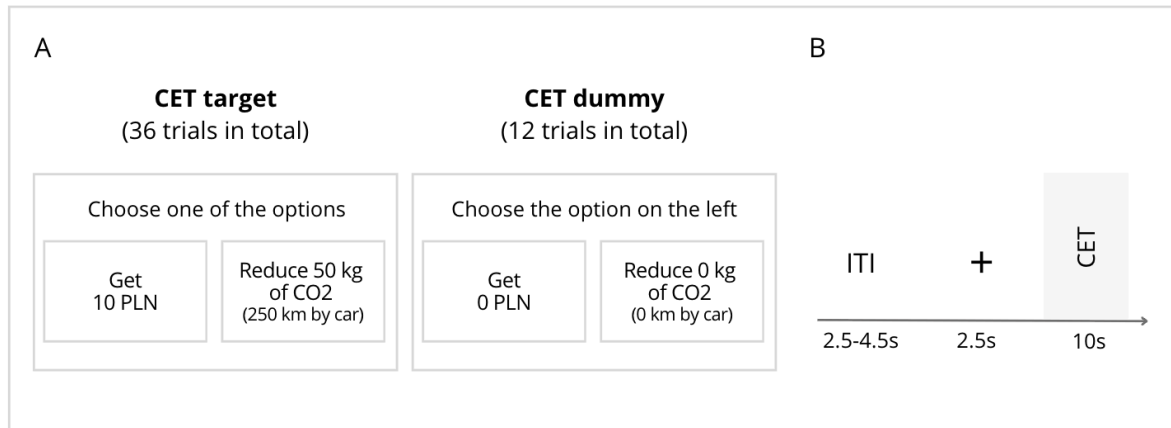


Figure 10. Carbon Emission Task (CET) overview. (A) Participants made binary choices between personal financial gain and CO₂ reduction. (B) Trial began with a fixation cue, followed by presentation of the choice options, with jittered intervals between trials.

Study design

Each participant was dynamically assigned to one of the 3 experimental conditions (ANGER, HOPE, or NEUTRAL) with the smallest number of observations at the given moment. In the whole 50-minute procedure, participants completed questionnaires outside the scanner, had their structural brain scans acquired, and then performed 3 runs of RRES and 1 run of CET during MRI. An overview of the procedure is provided in Fig. 11.

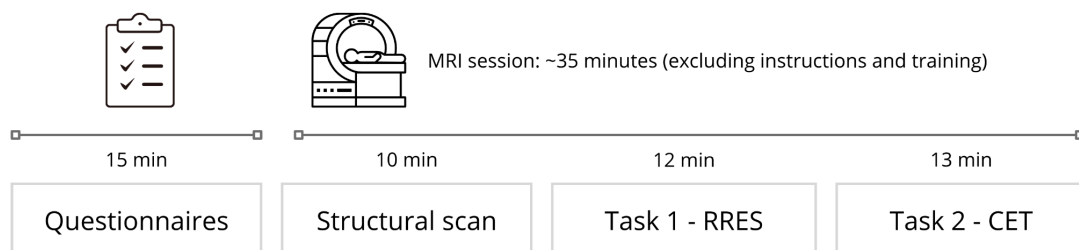


Figure 11. The overview of the experimental procedure of Study 4.

9.2.3. Image acquisition

Details of MRI acquisition parameters are reported in the data descriptor. Key parameters were TR=2000 ms, TE=30 ms, and 2.5 mm isotropic voxels for functional EPI.

9.2.4. fMRI analysis

Software and versions, the stages of preprocessing (fMRIPrep), and the first-level modelling (SPM12) follow the pipeline described in the data descriptor. Below, dissertation-specific first-level and group-level models, aligned with hypotheses, are detailed.

All neuroimaging analyses were carried out in SPM12 running on MATLAB 2023a, using preprocessed BOLD images in MNI152NLin2009cAsym space generated by fMRIPrep. For each task, first-level general linear models (GLMs) were estimated separately for each participant. Task regressors were convolved with the canonical hemodynamic response function. The design matrices included a high-pass filter with a 128s cut-off. For every run, nuisance regressors consisted of confound time series derived from fMRIPrep (including framewise displacement), which were preprocessed using the BIDS-Matlab toolbox. Participants with low signal quality or excessive head motion were excluded from analyses if they showed a temporal signal-to-noise ratio (tSNR) < 40 or more than 15% of volumes exceeding FD > 0.5 mm in any of the runs. All analyses used an explicit tissue-probability mask in MNI space; anatomical labels are based on the Neuromorphometrics atlas distributed with SPM12, unless noted otherwise, and all coordinates are reported in MNI space. For clarity, some clusters are additionally described using macro-anatomical labels (e.g., ventral striatum when referring to caudate and putamen). The correspondence between these macro-anatomical labels and Neuromorphometrics regions is provided in Table S6 (Supplementary Materials). Unless otherwise specified, all second-level models included mean framewise displacement (FD) as a covariate of no interest to account for residual motion effects (Bolton et al., 2020; Kay et al., 2025). Statistical inference was conducted using voxel-wise family-wise error (FWE) correction at $p < .05$ (cluster-forming threshold $k = 0$), and analyses were constrained to explicit masks.

First-level model: reading-related activity. To model brain activity associated with emotional stories about climate change, first-level GLMs were specified for the three story

presentation runs. Within each session, task regressors modelled the onset of target stories (TAR) and control stories (CON), using 15 s boxcar durations to cover the reading period (actual reading time was not recorded). A third regressor modelled the subsequent story rating periods (Q). For each participant, this model yielded first-level contrast images for TAR, CON, Q, and the differential contrasts $TAR > CON$ and $CON > TAR$.

Functional masking. To constrain second-level analyses to regions engaged during story reading, a functionally defined “story-processing mask” was derived from a group-level one-sample t-test on the TAR contrast (target stories versus implicit baseline) across all included participants, with mean FD as a covariate and the TPM brain mask as an explicit mask. The resulting map was thresholded at voxel-wise $pFWE < .05$ (positive activations) and binarised. This mask defined a task-relevant search space independent of subsequent between-group comparisons and was applied as an explicit mask.

Group-level analysis: Emotion effects during story reading (H2–H4). Individual $TAR > CON$ contrast images from all participants without excessive movement ($n=156$) were entered into a one-way between-subjects ANOVA with three groups (ANGER, HOPE, NEUTRAL). Planned contrasts included $(ANGER + HOPE) > NEUTRAL$, $ANGER > HOPE$, $ANGER > NEUTRAL$, $HOPE > ANGER$ and $HOPE > NEUTRAL$. These analyses tested whether emotionally evocative stories (anger and hope) elicited stronger activation than neutral stories in appraisal-related regions common to both emotions (H2), and whether anger and hope preferentially engaged networks associated with negative versus positive valence processing, respectively (H3–H4). Analyses were conducted within the story-processing mask.

First-level model: Climate-decision-related activity. To investigate general climate-decision-related activity, two regressors were specified: one modelled the onset of CET target trials and the other modelled the onset of dummy trials. Events were time-locked to the onset of the decision screen, and event durations were set to the participant’s response time (RT). The remaining post-response time within the trial was modelled separately using additional “leftover” regressors ($onset = onset + RT$; $duration = trial\ duration - RT$). The primary first-level contrast was $CET > dummy$.

Group-level analysis: Main effect of task (H5) and functional mask definition.

Individual CET > dummy contrast images from all participants without excessive movement (n=156) were entered into a second-level one-sample t-test across all included participants (with mean FD as a covariate). The resulting activation map, thresholded at voxel-wise pFWE < .05, defined the functionally informed “climate decision mask” used in subsequent analyses.

Group-level analysis: Emotion modulation of decision-related activity (H8). CET> dummy contrast images were entered into a one-way ANOVA with group as a between-subjects factor, within the climate decision mask. Participants with insufficient data quality (n = 6) and participants whose responses indicated a misunderstanding of the CET task (n = 2) were excluded, yielding a final sample of n = 152 (ANGER = 53, HOPE = 45, NEUTRAL = 54).

First-level model: Choice-specific activity. To investigate choice-specific activity, pro-environmental choices (PEB; choosing CO₂ reduction) and self-interest choices (SIB; choosing a monetary bonus) were modelled as separate regressors, in addition to dummy trials. Only participants who exhibited at least one PEB and one SIB decision were retained for first- and second-level analyses. Rational trials were excluded from the decision model and were not modelled as a separate regressor. They were omitted because, in these trials where one option objectively dominated, the participant’s choice cannot be interpreted as reflecting how they weighed climate benefits against personal gain. Event onsets were time-locked to the onset of the choice screen, and event durations were set to the participant’s response time (RT). The remaining post-response period was modelled with additional condition-specific “leftover” regressors (onset = onset + RT; duration = trial duration – RT). For each participant, this model yielded first-level contrast images for PEB > SIB and SIB > PEB.

Group-level analysis: The effect of choice type (H6). To test whether pro-environmental choices engaged brain regions associated with self-control - particularly the DLPFC - contrast images for PEB > SIB were entered into a second-level one-sample t-test across all included participants (with mean FD as a covariate). Some participants were excluded due to insufficient data quality (n = 6), response patterns indicative of misunderstanding of task instructions (n = 2), and lack of decision variability (n = 20), yielding a final sample of n = 133.

Group-level analysis: Emotion modulation of choice-related activity (H9). To test whether emotional framing modulated the differentiation in brain activity between pro-environmental and self-interest choices, PEB > SIB contrast was entered into second-level one-way ANOVA with group as a between-subjects factor. Effects in the opposite direction, SIB > PEB, were assessed by testing the negative direction of the same PEB > SIB contrast at the second level.. Participants with low data quality (n = 6) and response patterns indicating misunderstanding of task instructions (n = 2) were excluded first. Participants without sufficient decision variability to estimate the PEB > SIB contrast were then excluded. This exclusion list contained 20 participants, one of whom had already been removed for poor data quality, resulting in 19 additional exclusions. The final sample included n = 133 participants: n = 47 in the ANGER group, n = 44 in the HOPE group, and n = 42 in the NEUTRAL group.

Individual differences: Climate emotions predicting choice-related activation (H11). To test whether self-reported baseline climate emotions predicted brain activity differentiation between PEB and SIB, the PEB > SIB contrast was entered into a second-level regression model. The predictors for this model were selected on the basis of the preceding behavioural analysis: ICE subscales that were significantly associated with PEB were entered as predictors of PEB > SIB choice-related activation. To avoid confounding individual differences in baseline climate emotions with experimentally induced emotions, this analysis was limited to the NEUTRAL group (n = 52). Participants with poor data quality (n = 4) or absence of one choice type (n = 6) were excluded, resulting in a final sample of n = 42. A predefined climate decision mask was applied.

9.3. Results

9.3.1. Climate emotions - behaviour and brain activity

Behavioural results

To assess whether the emotional stories in the RRES task elicited the intended emotions, story ratings were compared within and between groups (H1). Hypothesis 1 was supported, and the pattern of ratings of valence and arousal followed previous results (Fig. 12). A repeated-measures ANOVA on arousal showed a significant group-by-story-type

interaction, $F(2,157) = 56.02$, $p < .0001$, partial $\eta^2 = .42$. Tukey-adjusted pairwise comparisons showed that NEU stories were less arousing than ANG ($\Delta\text{NEU-ANG} = -1.99$, $p_{\text{adj}} < .001$) and HOP ($\Delta\text{NEU-HOP} = -1.74$, $p_{\text{adj}} < .001$), whereas ANG and HOP did not differ ($\Delta\text{ANG-HOP} = .25$, $p_{\text{adj}} = .970$). As expected, no arousal difference was observed between target and control stories in the NEU condition ($\Delta\text{target-control} = .15$, $p_{\text{adj}} = .980$). For valence, the group-by-story-type interaction was also significant, $F(2,157) = 335.69$, $p < .001$, partial $\eta^2 = .81$. Tukey-adjusted comparisons showed that HOP stories were rated more positively than NEU ($\Delta\text{HOP-NEU} = 1.78$, $p_{\text{adj}} < .001$) and ANG ($\Delta\text{HOP-ANG} = 5.50$, $p_{\text{adj}} < .001$), and that ANG stories were rated more negatively than NEU ($\Delta\text{ANG-NEU} = -3.72$, $p_{\text{adj}} < .001$). No valence difference between target and control stories in the NEU condition was observed ($\Delta\text{target-control} = -.36$, $p_{\text{adj}} = .197$).

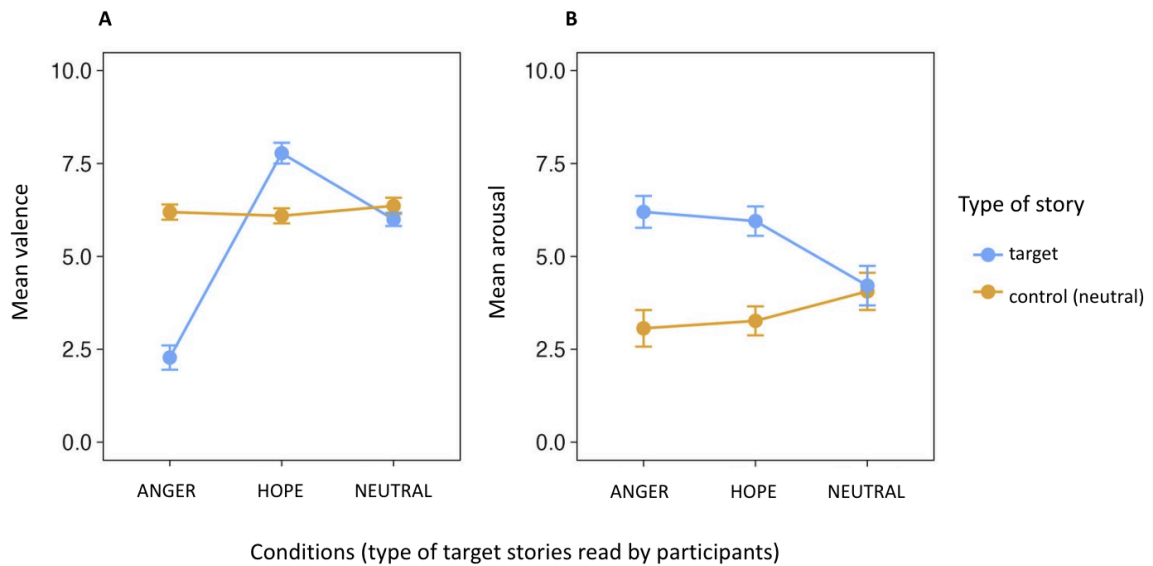


Figure 12. Mean story ratings for (A) valence and (B) arousal. Error bars represent 95% confidence intervals.

Neuroimaging results

At the level of brain activity, activation within common appraisal-related regions (see section 5.6.2) was expected to be stronger in the groups exposed to stories evoking anger and hope than in the group exposed to neutral stories (H2).

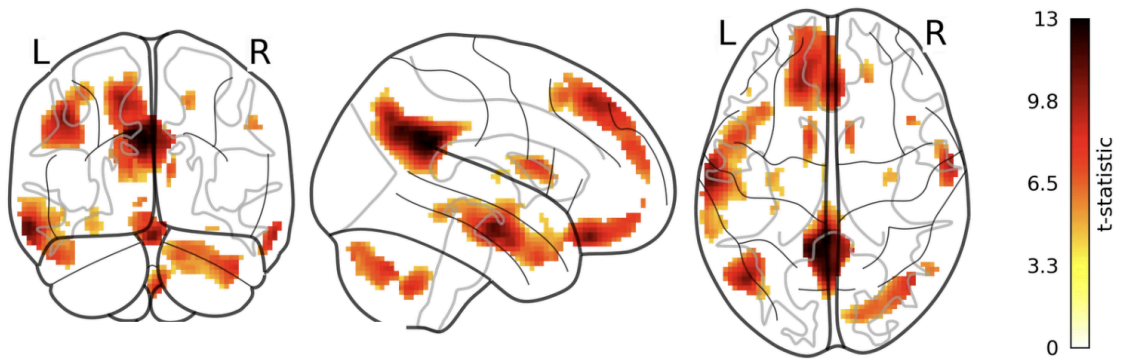
Focus is placed on a priori comparisons directly related to hypotheses H2–H4: $\text{ANG} + \text{HOP} > \text{NEU}$ (weights $[0.5 \ 0.5 \ -1]$), $\text{ANG} > \text{HOP}$, and $\text{HOP} > \text{ANG}$. The contrast ($\text{ANG} +$

HOP) > NEU revealed multiple significant clusters with peaks in the posterior cingulate cortex, medial and superior frontal cortex, bilateral middle temporal cortex, right temporal pole, and angular gyrus, together with subcortical clusters in the bilateral caudate and hippocampus, as well as cerebellar clusters (Fig. 13a, Table S7). This pattern supports H2 by showing that emotional climate stories, compared with neutral stories, produced stronger activation in brain regions involved in appraisal-related processing.

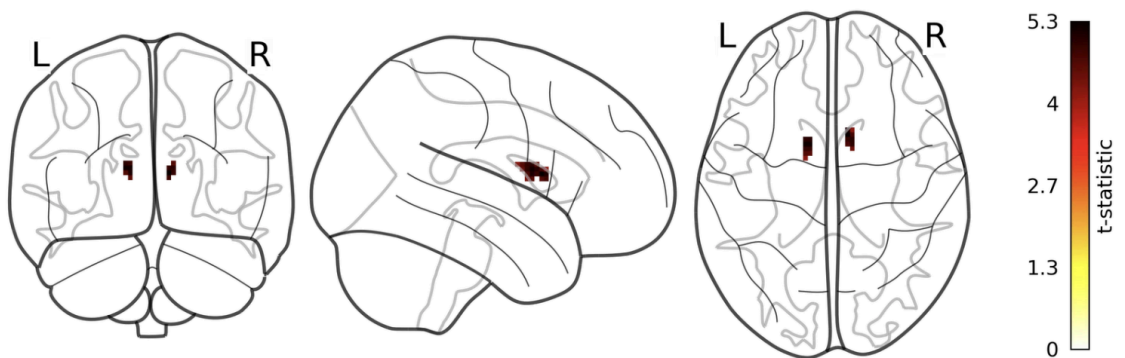
Direct group comparisons within the ANOVA revealed emotion-specific effects. We expected preferential engagement of networks involved in the processing of negative valence when reading ANG stories (H3). In the ANG > HOP contrast, two small clusters were observed in the caudate nucleus, with peaks at [9, 10, 12], $k = 14$ and [-14, 6, 14], $k = 24$ (Fig. 13b, Table S8). H3 was thus partially supported.

We expected preferential engagement of networks supporting positive valence when reading HOP stories (H4). The HOP > ANG contrast revealed two clusters in the occipital pole, peaks at [-6, -102, 4], $k = 12$ and [14, -97, 10], $k = 10$ (Fig. 13c, Table S9). Because these effects were limited to occipital regions and did not involve the expected networks supporting positive valence, H4 was not supported.

A ANGER + HOPE > NEUTRAL



B ANGER > HOPE



C HOPE > ANGER

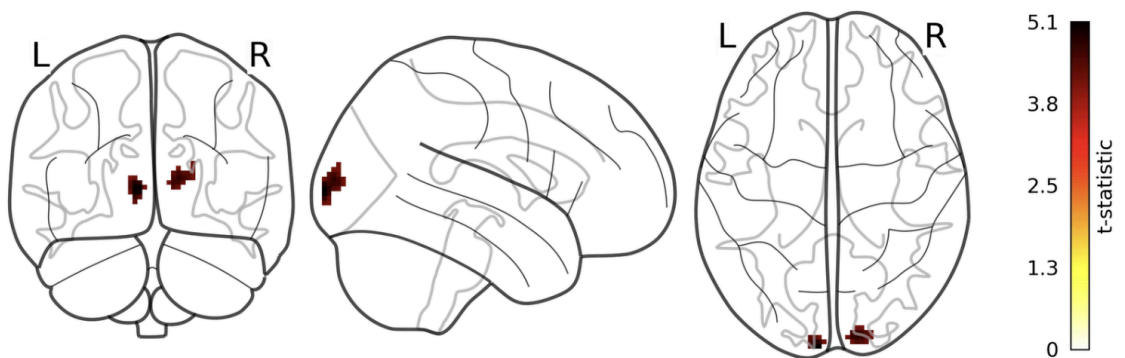


Figure 13. Whole-brain group comparisons in the RRES task. A whole-brain statistical parametric map showing regions with greater activation for three a priori contrasts A) ANGER + HOPE > NEUTRAL, B) ANGER > HOPE, C) HOPE > ANGER. Abbreviations: PCC/PCu = posterior cingulate cortex/precuneus; MFC = medial frontal cortex; MTG = middle temporal gyrus; Caud = caudate nucleus; OCP = occipital pole. The colour bar shows T values. L/R, left/right.

9.3.2. Climate-relevant decisions - behaviour and brain activity

Behavioral results

Behavioural effects in the CET have been described in detail in a separate data descriptor publication. Consistent with the original validation study, climate-friendly choices decreased linearly with higher monetary bonuses and increased linearly with larger CO₂ emission reductions (Zaremba, Kossowski, et al., 2025).

Neuroimaging results

Climate-related decision-making was expected to engage brain networks associated with valuation, action selection, and cognitive control (H5). The CET > dummy contrast revealed a large cluster peaking in the left medial frontal region, peak at $[-6, 26, 37]$, $k = 2908$. Additional peaks were located in the left anterior insula, posterior cingulate/precuneus, right dorsolateral and superior frontal cortex, and right medial orbitofrontal cortex and left inferior frontal gyrus (Figure 14, Table S10). This activation pattern is consistent with the expected engagement of regions implicated in valuation, action selection, and cognitive control. Thus, H5 was supported.

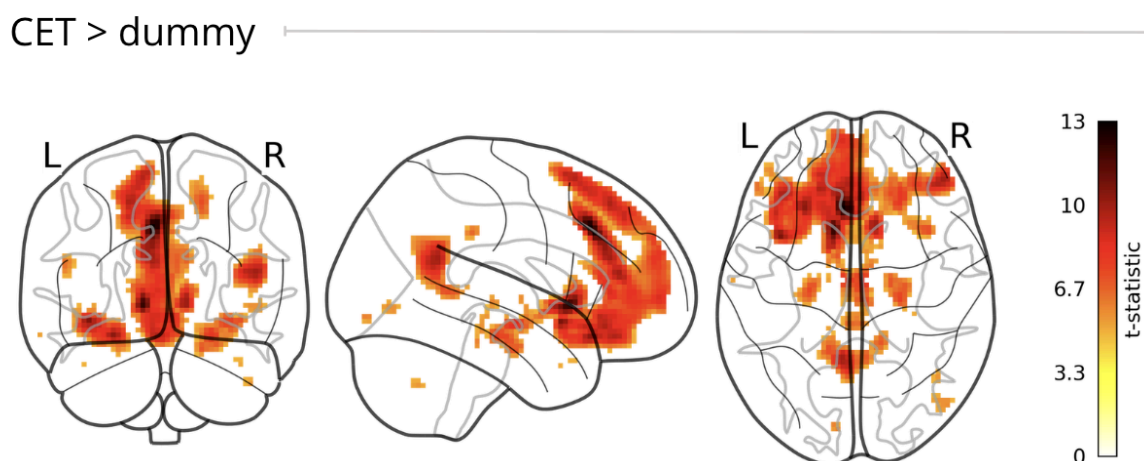


Figure 14. Whole-brain group comparison of brain activity during climate-related decision-making (CET > dummy). A whole-brain statistical parametric map showing regions with greater activation during climate-related decision trials than during dummy trials. The colour bar shows T values. L/R, left/right.

Differential engagement of control- and valuation-related brain regions was expected during pro-environmental (PEB) versus self-interest choices (SIB) (H6). Based on previous findings, greater involvement of the lateral prefrontal cortex - particularly the dorsolateral prefrontal cortex (DLPFC) - was anticipated during PEB relative to SIB (Baumgartner et al., 2025; Guizar Rosales et al., 2022).

The PEB > SIB contrast yielded very small effects, with three clusters (largest $k = 12$). Peaks were located in the left fusiform gyrus (peak at $[-16, -84, -10]$, $k = 12$), the right middle frontal gyrus ($[49, 38, 24]$; $k = 6$), and the left cerebellum ($[-41, -67, -43]$; $k = 2$) (Figure 15a; Table S11). The reverse contrast (SIB > PEB) showed two clusters in anterior cingulate gyrus ($[-6, 23, -6]$; $k = 119$, and $[-1, 40, 0]$; $k = 20$), medial frontal cortex ($[-8, 53, -10]$; $k = 3$), and a peak in hippocampus ($[-28, -32, -10]$; $k = 1$) (Figure 15b; Table S12). Thus, although small clusters were observed in the PEB > SIB contrast, the pattern did not provide clear support for the predicted preferential engagement of control- and valuation-related regions during pro-environmental choices. Therefore, H6 was not supported.

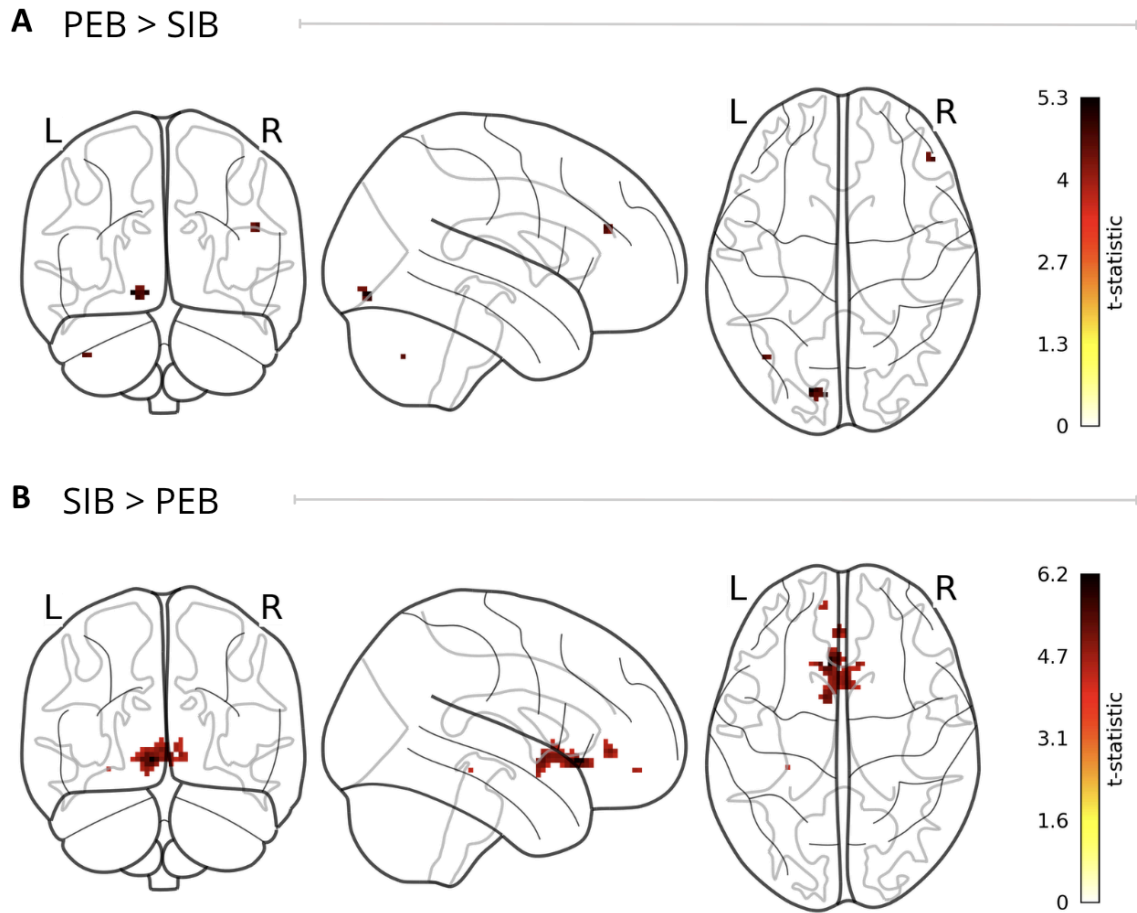


Figure 15. Whole-brain group comparison of brain activity during pro-environmental and self-interest choices. Whole-brain statistical parametric maps showing regions with greater activation for two a priori contrasts A) pro-environmental choices relative to self-interest choices (PEB > SIB) and B) self-interest choices relative to pro-environmental choices (SIB > PEB). The colour bar shows T values. L/R, left/right.

9.3.3. Effects of emotion manipulation on PEB and brain activity

This section examines whether prior exposure to emotional climate-related narratives modulated climate-relevant behaviour and the associated brain activity. Specifically, it tested whether emotional (anger- or hope-inducing) stimuli increased PEB relative to neutral stimuli (H7), whether emotional stimuli modulated brain activity during climate-relevant decisions (H8), and whether emotional stimuli altered the brain differentiation between pro-environmental and self-interest choices (H9). No directional hypotheses were formulated regarding differences between anger and hope conditions.

Because, according to existing evidence, anger- and hope-evoking stimuli might both be effective in eliciting PEB, their comparison should be viewed as exploratory (Geiger et al., 2023; Gregersen et al., 2023; Stanley et al., 2021).

Behavioural results

The proportion of PEB in the Carbon Emission Task (CET) was expected to be higher in the groups exposed to emotional stories than neutral stories (H7). Group differences in the proportion of PEB in the CET were tested using a one-way ANOVA ($n = 160$). H7 was not supported; the omnibus effect of the group was not significant, $F(2, 157) = .90$, $p = .41$, $\eta^2 = .01$. Descriptive statistics indicated that, irrespective of experimental condition, participants chose the PEB in approximately half of the trials (ANGER: $M = .55$, $SD = .19$, $n = 54$; HOPE: $M = .51$, $SD = .19$, $n = 54$; NEUTRAL: $M = .51$, $SD = .18$, $n = 52$). The empirical probability of choosing a pro-environmental option is shown in Figure 16.

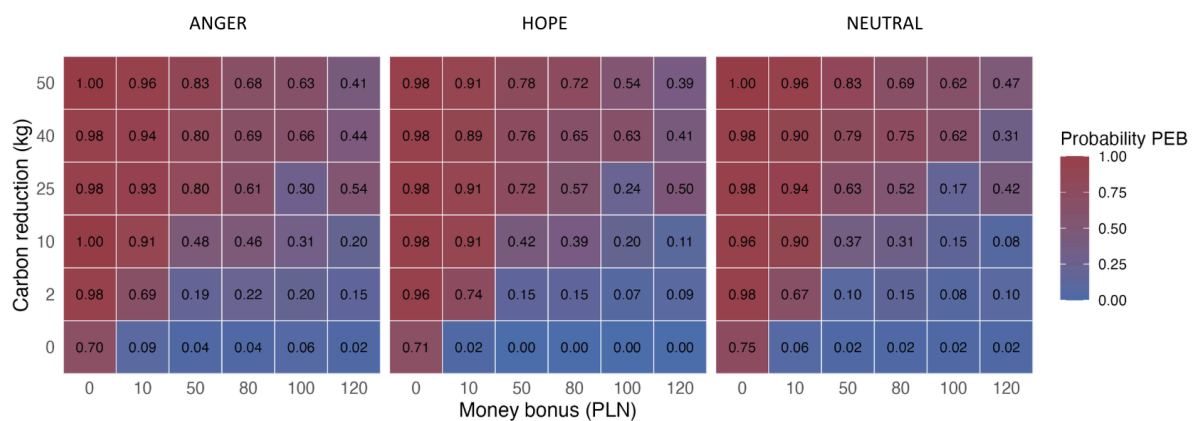


Figure 16. Empirical probability of choosing the PEB option in the Carbon Emission Task. Cell values represent the empirical probability of choosing the PEB, across trials, for each combination of monetary bonus and CO₂ reduction level, separately for each experimental group.

Neuroimaging results

Decision-related activation during the CET was compared between participants previously exposed to emotional climate stories and those exposed to neutral stories. Participants in the ANG and HOP groups were expected to show greater activation in the predefined ROIs than participants in the NEU group (H8). On the whole-brain level, the omnibus ANOVA revealed a significant main effect of condition within the climate decision mask. However, the planned directional contrast comparing emotional to neutral conditions (ANGER + HOPE > NEUTRAL) revealed no suprathreshold clusters (Fig. 17). Neither of the

exploratory pairwise comparisons (ANGER > NEUTRAL, HOPE > NEUTRAL, ANGER > HOPE, HOPE > ANGER) showed suprathreshold clusters. Visual inspection of uncorrected maps ($p < .001$, $k = 0$) revealed small, scattered foci for several contrasts; none survived multiple-comparison correction, and they are not interpreted further. Therefore, H8 was not supported.

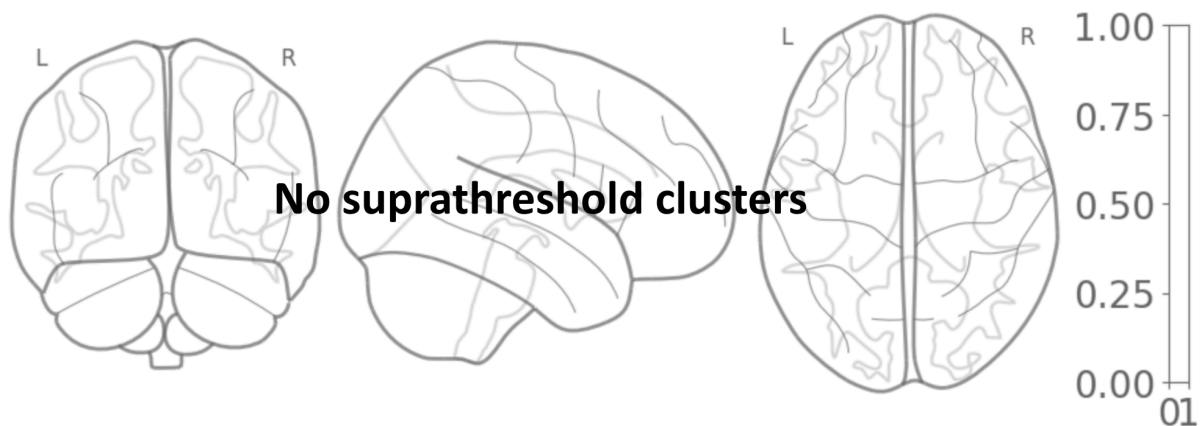


Figure 17. Whole-brain effects of group on climate-relevant decision-making in CET for the ANGER + HOPE > NEUTRAL contrast. No suprathreshold clusters were found. Statistical maps are thresholded at voxel-wise FWE-corrected $p < .05$.

H9 tested whether prior exposure to emotional climate stories modulated the brain activity in pro-environmental and self-interested choices. Specifically, participants in the ANG, HOP, and NEU groups were compared on the PEB > SIB and SIB > PEB contrasts within the predefined climate decision mask (H9). A whole-brain one-way between-subjects ANOVA on the PEB > SIB contrast revealed a significant main effect of condition within the climate decision mask. However, the planned directional contrast ANGER + HOPE > NEUTRAL revealed no clusters surviving voxel-wise FWE correction at $p < .05$. Likewise, none of the planned pairwise t-contrasts (ANGER > NEUTRAL, HOPE > NEUTRAL) or contrasts between the emotional conditions (ANGER > HOPE, HOPE > ANGER) showed suprathreshold cluster (Fig.18). H9 was not supported.

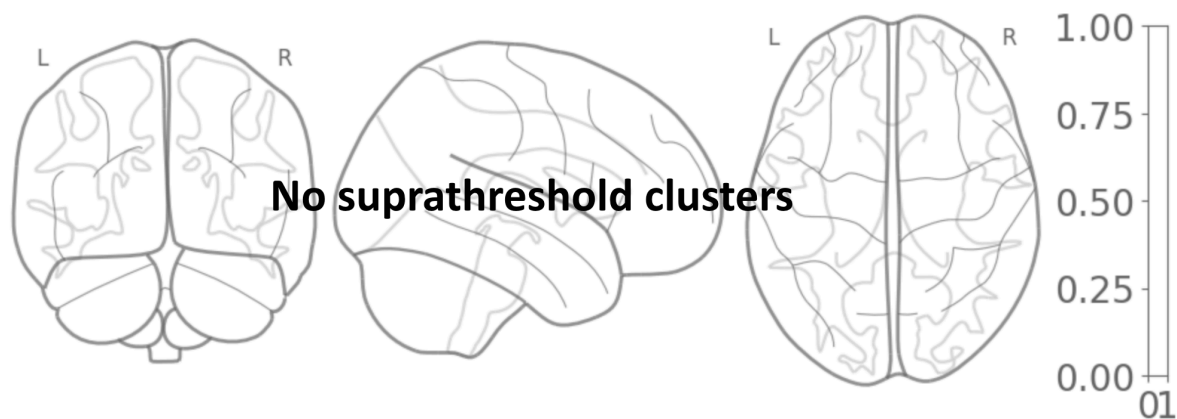


Figure 18. Whole-brain effects of group on choice-specific activity in CET for the ANGER + HOPE > NEUTRAL contrast. No suprathreshold clusters were found. Statistical maps are thresholded at voxel-wise FWE-corrected $p < .05$.

9.3.4. Baseline climate emotions and PEB

This section examines how individual differences in self-reported baseline climate emotions contribute to PEB and its brain correlates during climate-related choices. Behavioural analyses focus on the role of baseline climate emotions assessed prior to experimental manipulation (H10). Neuroimaging analyses focus on the role of baseline climate emotions in modulating brain activity during PEB (H11). For methodological clarity, the following analyses were limited to participants unaffected by emotional manipulation (NEUTRAL group).

Behavioral results

Before examining whether individual differences in climate emotions were associated with PEB or brain activity during climate-related decisions, we confirmed that baseline ICE profiles were comparable across groups (see Fig. 19). As reported in earlier work, no significant between-group differences were observed on any ICE subscale (Zaremba, Kossowski, et al., 2025).

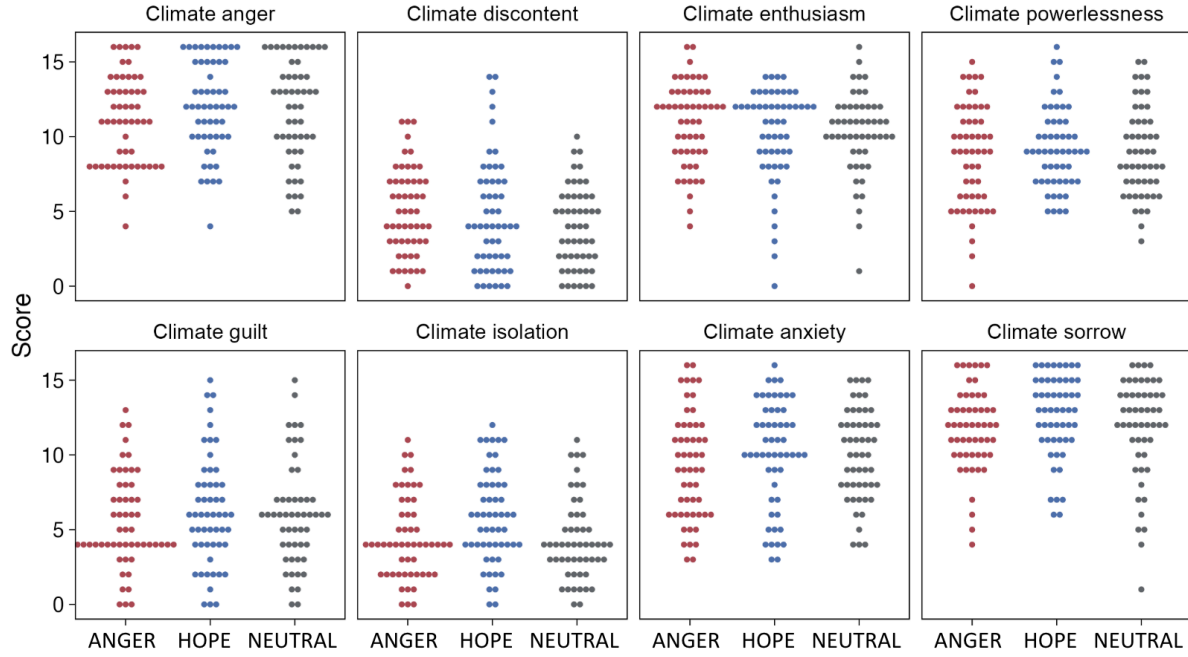


Figure 19. Distribution of ICE subscales scores across experimental groups. No statistically significant between-group differences in mean ICE scores were observed.

The relationship between the baseline level of eight distinct climate emotions and climate-related decision-making in the CET was examined. PEB was operationalised as the proportion of climate-friendly choices in trials that required participants to weigh climate benefit against personal monetary gain. Trials with an objectively dominant option were excluded, because choices in these trials could not be interpreted as reflecting this trade-off. A preliminary analysis indicated deviations from normality, leading to the decision to apply Spearman's rank correlations for all tests.

Across the eight ICE subscales, only climate anger showed a reliable positive association with PEB choices (Spearman's $\rho = .55$, $p < .001$, $qFDR < .01$). Climate guilt was nominally significant ($p = .05$), but did not survive FDR correction ($qFDR = .19$). Partial correlations controlling for the remaining ICE subscales showed that climate anger remained a significant positive correlate of PEB ($\rho = .52$, $p < .001$, $qFDR < .01$). In addition, climate enthusiasm showed a significant negative correlation ($\rho = -.49$, $p < .001$, $qFDR < .01$). All other partial correlations were not significant. Full results are reported in Table 5. These findings support H10, indicating that baseline climate anger was reliably associated with climate-friendly choices in the CET.

Table 5. Spearman's correlations and partial correlations between ICE subscales and proportion of PEB choices in the NEUTRAL group (N = 42). FDR-corrected q values across eight partial-correlation tests.

ICE score	ρ	p	q (FDR)	partial ρ	partial p	partial q (FDR)
Anger	.55	<.001***	<.01*	.52	<.001***	<.01*
Guilt	.30	.05*	.19	.22	.16	.33
Sorrow	.27	.09	.19	-.08	.63	.84
Discontent	-.18	.26	.39	.00	.98	.98
Anxiety	.17	.29	.39	.15	.35	.56
Enthusiasm	-.26	.10	.19	-.49	<.001***	<.01*
Powerlessness	.15	.35	.40	-.05	.73	.84
Isolation	.04	.79	.79	-.22	.17	.33

Neuroimaging results

It was hypothesised that individual differences in baseline climate emotions were associated with differential brain activity during climate-related decisions. Because climate anger was the only ICE subscale that was significantly and positively associated with PEB after correction for multiple comparisons, subsequent fMRI analyses were restricted to this subscale. This restriction was also consistent with the theoretical view of climate anger as an action-oriented, moralised form of engagement, likely to influence valuation-related processing when choosing between personal gain and climate benefit. Accordingly, it was tested whether higher climate anger was associated with stronger PEB > SIB responses in valuation-related regions, particularly VMPFC and ventral striatum.

At the voxel-wise FWE threshold ($p_{FWE} < .05$), no suprathreshold voxels were observed for the association between ICE climate anger score and the PEB > SIB contrast. Therefore, H11 was not supported.

9.4. Discussion

9.4.1. Overview

Study 4 was among the first neuroimaging studies to examine how climate emotions relate to climate-relevant decision-making. Climate anger and hope were treated as constructed from appraisal patterns linked to multiple cognitive processes and brain regions. Across

hypotheses, the results showed a coherent pattern. The climate emotion induction was effective at the subjective level and engaged appraisal-related brain areas during story reading, but it did not affect PEB or decision-related brain activity. Finally, the findings pointed to a distinction between induced and more stable baseline climate emotions: baseline climate anger predicted PEB, whereas briefly induced anger and hope did not. However, this behavioural association was not reflected at the brain activity level, as baseline climate anger did not significantly predict PEB > SIB choice-related activation.

9.4.2. Climate emotion induction and appraisal-related brain activity

Hypothesis 1 (supported) concerned the effectiveness of the emotion induction, which first had to be established before testing whether climate emotions influenced behaviour. The emotional stories differed from neutral stories in arousal ratings, and the hope and anger stories differed from each other in valence in the expected directions (Zaremba et al., 2024). This indicates that the ECCS can elicit emotions in the scanner, supporting its ecological validity in this context.

Hypothesis 2 (supported) concerned brain activity during emotional versus neutral comparisons while reading stories. Increased activity was observed in a number of brain regions, including ventral occipitotemporal cortex, inferior and orbitofrontal cortices, superior and middle temporal gyri (including angular gyrus), precuneus/posterior cingulate cortex, anterior insula, and cerebellum. This broad activation pattern is consistent with the cognitive appraisal framework introduced earlier in the thesis, in which emotional climate narratives were expected to engage relevance detection and salience processes, as well as the assessment of causality, implications, coping potential, and normative significance (Sander et al., 2018). Consistent with the literature, the observed brain activation in the temporal cortex and angular gyrus can be linked to semantic integration and social-cognitive processing during comprehension of conceptually rich narratives (Schurz et al., 2021; Seghier, 2013). The posterior cingulate cortex and precuneus are commonly implicated in self-referential and mentalizing-related processing, which is central to appraising the implications and personal meaning of events described in stories (DiNicola et al., 2020; Schurz et al., 2021). The engagement of anterior insula is consistent with increased salience and affective relevance of emotional stories, which is in line with earlier

findings that thinking about environmental destruction recruits this region (Sawe & Knutson, 2015; Uddin et al., 2017).

The strong overlap in brain activity for anger and hope relative to the neutral condition does not imply that these climate emotions were psychologically identical. Anger and hope are distinct experiences, differing in subjective quality, motivational orientation, and often behavioural consequences. However, the overlap is consistent with the idea that, within this paradigm, both emotions rely on partly shared appraisal processes and therefore engage a common set of brain regions (Sander et al., 2018). Regardless of group assignment, participants had to evaluate who or what caused the events, how normatively significant those events were, and what they implied for collective outcomes and future possibilities. Because such appraisals are central to the elicitation of both emotions, it is plausible that they recruited overlapping brain regions. The absence of expected activation in the amygdala is also theoretically informative. The amygdala is often described as a key region for relevance detection, and it has also been linked to processing threat and negatively valenced emotions (Stussi & Sander, 2024; Varkevisser et al., 2024). In the present study, however, appraisal-sensitive responses were more apparent in medial temporal and temporoparietal structures, including hippocampus, temporal pole, and TPJ. This pattern suggests that climate-emotion-related appraisals may depend less on the rapid detection of salient emotional cues and more on semantic, social-cognitive, and self-referential processes involved in construing agency, implications, and personal meaning (Brosch & Sander, 2013; DiNicola et al., 2020; Schurz et al., 2021). Such an interpretation fits the demands of the RRES task, in which participants had to interpret the social and moral meaning of extended narratives rather than react to brief, intense perceptual stimuli that most reliably engage the amygdala.

Hypothesis 3 (partially supported) concerned anger-specific brain activity during story reading. The main differentiation reported for ANGER > HOPE was a focal cluster in the right caudate/dorsal striatum. This result is consistent with the broader literature linking dorsal striatum to action selection and approach-related motivational processes (Bartra et al., 2013), and with climate anger being associated with a readiness to act in response to perceived wrongdoing or moral transgression (Gregersen et al., 2023, 2025; Stanley et al., 2021). In the context of climate narratives, stronger caudate engagement during anger may reflect increased recruitment of systems involved in action selection and responses to

perceived norm violation, fitting the action-oriented profile of climate anger and aligning with earlier moral-emotion studies that linked moral transgression processing to dorsal striatal or caudate activity alongside temporal and temporoparietal regions (Kédia et al., 2008; Khoudary et al., 2022; Parkinson et al., 2011).

Hypothesis 4 (not supported) concerned hope-specific brain activity during story reading. The HOPE > ANGER contrast showed two clusters in the occipital pole rather than in the anticipated regions implicated in valuation or future-oriented appraisal. Given the small size ($k = 12$ and 10) and unexpected posterior location of these effects, they should be interpreted cautiously and not treated as evidence for a specific brain mechanism of climate hope. One plausible explanation is that hope stories elicited stronger visual attention or mental imagery during reading, for example, if positively valenced, future-oriented content encouraged more vivid imagination (Liu et al., 2022).

9.4.3. Brain activity during climate-relevant decisions

Hypothesis 5 (supported) concerned whether CET engages brain regions associated with decision-making processes, especially valuation, action selection, and cognitive control. Activations were found in regions involved in salience, control, and valuation, including anterior insula, medial frontal and lateral prefrontal areas, and medial orbitofrontal cortex, as well as subcortical structures involved in action selection, including thalamus and striatum. These results are in line with value-based decision-making models, in which choices depend on integrating multiple attributes, including personal costs, environmental benefits, and action constraints (Cutler & Campbell-Meiklejohn, 2019; Levy & Glimcher, 2012; S. Wang & van den Berg, 2021). Lateral and medial frontal cortices likely support control and weighting of these attributes, whereas anterior insula activity may reflect the salience of the choice conflict (Bellucci et al., 2020; FeldmanHall & Heffner, 2022). Posterior cingulate/precuneus and medial temporal activity suggest that self-referential processes also play a role in CET decisions (Bzdok et al., 2012; Obeso et al., 2018; Schurz et al., 2021). This interpretation is also consistent with work suggesting that sustainable choices may involve prospective thinking about future outcomes, valuation of delayed consequences, and perceived responsibility for the effects of one's actions (Brevers et al., 2021; Villa et al., 2025). Overall, these findings are consistent with the view that CET

recruits regions supporting salience detection, cognitive control, and response preparation, and they support the construct validity of the CET as an fMRI-compatible measure of consequential climate-relevant choice.

Hypothesis 6 (not supported) concerned whether pro-environmental versus self-interest choices show distinct patterns of brain activity, especially greater involvement of brain regions implicated in self-control, such as DLPFC. The PEB > SIB contrast revealed very small effects and only one cluster aligned with the prediction in the right middle frontal gyrus. However, the size ($k = 6$) and extent of this cluster do not support the expectation of robust DLPFC engagement for pro-environmental choices. Stronger and more reliable differentiation emerged for self-interest choices. Two clusters with peaks in the anterior cingulate gyrus, and additional peaks in the medial frontal cortex and hippocampus were found in the reverse contrast SIB > PEB. These regions are commonly implicated in conflict monitoring, action selection or contextual processing (Bellucci et al., 2020; DiNicola et al., 2020). Although the increase in lateral prefrontal engagement was observed in the CET > dummy contrast, it was not related specifically to PEB or SIB choices. Both types of behaviour may draw on several partly overlapping mechanisms, including prospective thinking, valuation of delayed outcomes, perspective-taking toward distant others, and perceived responsibility for action outcomes (Brevers et al., 2021; Burns et al., 2022). These processes may have been engaged by the CET decision context as a whole, rather than being selectively expressed in the categorical contrast between pro-environmental and self-interest choices. This result is also consistent with an issue raised in the prosocial decision literature, which broadly links regions such as VMPFC, ACC, and insula with costly prosocial decisions, but emphasises that design differences strongly affect what can be detected at the group level (Yang & Li, 2025). In this context, the broad CET > dummy engagement supports the construct validity of the CET task adapted for fMRI. At the same time, the weak PEB > SIB effects point to the limits of the methodology used to isolate the processes that differentiate pro-environmental from self-interest choices.

9.4.4. Effects of induced climate emotions on climate-relevant decisions

Hypothesis 7, which predicted that emotional climate stimuli would increase pro-environmental behaviour relative to neutral stimuli, was not supported. The group differences in the proportion of PEB in the CET were not significant. This null effect occurred despite the successful induction of target climate emotions. The most direct conclusion is that, in this design, a brief emotion induction did not increase PEB. Consistent with the behavioural results, brain-activity-focused Hypotheses 8 and 9 were also not supported. Between-group differences were not observed in either CET > dummy, nor in PEB > SIB and SIB > PEB contrasts.

This result converges with the findings of Study 3. In that study, the effectiveness of the experimental manipulation was also confirmed, yet eliciting climate anger and climate hope did not increase PEB. Importantly, Studies 3 and 4 differed in several design features that could, in principle, have affected sensitivity to emotion manipulation. First, although both studies used ECCS stories, exposure differed: in Study 3, participants read at their own pace, whereas in Study 4, stories were presented for a fixed duration (15 seconds). Second, while the stories largely overlapped, the number of stories presented varied across studies. Third, Study 3 was conducted online, requiring relatively little effort to participate, whereas Study 4 involved volunteering for an fMRI scan, travelling to the lab, and completing a demanding procedure. Study 3 used broader purposive samples in Poland and Norway that approximated national distributions for age, gender, and education, and intentionally represented different levels of climate change concern. Study 4 used a narrower sample of young adults (20–25 years) pre-selected for moderate climate change concern. Finally, the outcome measures differed. Study 3 operationalised PEB as time/cognitive effort and monetary donations, whereas Study 4 used a monetised trade-off task in a zero-sum choice context. Despite these differences in stimulus exposure, sampling, and behavioural operationalisation, the main result was the same - short induction of climate emotions did not significantly impact PEB.

This convergence supports the conclusion that the impact of brief climate emotion inductions on these types of PEB is limited and not easily generalisable across task contexts, a pattern also consistent with earlier experimental work showing that incidental

emotions do not uniformly increase PEB (Chapman et al., 2017; Ibanez et al., 2017) and with recent large-scale evidence that short climate interventions can shift some attitudes without increasing costly PEB (Voelkel et al., 2026). At the same time, the above conclusion should be interpreted as a boundary condition rather than as evidence that emotions are generally ineffective in motivating PEB. Current literature, despite pointing to important methodological problems in PEB research, including the widespread use of declarative measures and weak behavioural operationalisations, consistently identifies emotions as one of the key predictors of PEB and other climate-relevant outcomes (Brosch, 2021; Carrus et al., 2021; Goldberg et al., 2021; van Valkengoed & Steg, 2019; Xie et al., 2019). This makes it important to examine more closely the design features that may have limited such effects in the present study.

First, the stories clearly elicited emotional responses during reading, but the resulting emotional state may not have been strong enough, or sustained enough, to influence subsequent behaviour in the CET. Significant activations in appraisal-related brain regions were observed during story reading, but the induced state may have diminished quickly due to several features of the experimental design. Prior work on affect labelling suggests that putting feelings into words can dampen emotional reactivity, including reduced amygdala responses to negative stimuli (Lieberman et al., 2007). By asking participants to rate valence and arousal in RRES, the procedure may have shifted attention towards evaluation rather than full affective immersion. Furthermore, CET was preceded by an extended instruction and training phase, necessary for participants to understand the task logic, response mapping, and the meaning of the trade-offs. It likely required attention and rule learning, thereby inducing a significant cognitive load between the emotion induction and the decision phase (Plass & Kalyuga, 2019; Van Dillen et al., 2009). In another study using the ECCS, effects on several forms of climate-related action were observed in a design where the behavioural outcomes were measured directly after the intervention phase (Goldwert et al., 2026). This interpretation is consistent with evidence that the behavioural effects of emotional manipulations can weaken after a delay or distraction (D. Schwartz & Loewenstein, 2017).

Second, climate emotions may be relatively “cold” compared with emotions elicited by immediate personal events. Anger and hope in the climate domain often involve abstract, temporally extended consequences. Such states can be subjectively strong, but they may be

less likely to act as short-lived action triggers. This interpretation is consistent with the lack of observable amygdala activity in a contrast between emotional and neutral stories. In affective neuroscience, the amygdala responds most reliably to cues that are more immediate and biologically salient, such as threat-related facial expressions (Vuilleumier et al., 2001). Considering that the CET itself is an emotionally loaded task, this explanation becomes even more plausible. Decisions in the CET are individual, monetised, and parametrised trade-offs that can evoke guilt or “warm glow” associated with giving, as well as conflict between self-interest and norms (Berger & Wyss, 2021; Shipley & van Riper, 2022). In the emotion and decision-making literature, this kind of task-evoked response would be understood as an integral affect, that is, affect generated by the choice context itself, in contrast to incidental affect, which is carried over from another source (FeldmanHall & Heffner, 2022). The narratives elicited emotion via appraisals, but subsequent CET was not affectively neutral: it required participants to make consequential trade-offs involving personal benefit, environmental cost, and moral conflict. Instead, the task likely generated its own emotional and motivational signals, reducing sensitivity to the prior manipulation (Yang & Li, 2025). However, the same critique can be raised to any PEB task: each imposes its own action format, incentive structure, and situational demands, which may shape the immediate emotional context in which choices are made (FeldmanHall & Heffner, 2022). Incidental emotions are less likely to influence choices when the decision task is already emotionally engaging. In such contexts, emotions generated by the decision itself may dominate over affect carried over from an earlier manipulation (Västfjäll et al., 2016). This suggests that emotion manipulations may be more effective when embedded directly in the behavioural task, so that elicited appraisals remain aligned with the moment of decision (Berger & Wyss, 2021).

9.4.5. Baseline climate anger and climate-relevant decisions

The null experimental effects stand in useful contrast to the correlational associations observed for ICE climate emotions, suggesting that baseline climate emotions may be more relevant to real-world PEB. Hypothesis 10 (supported) concerned the potential role of more trait-like climate emotions in climate-relevant decision-making during the CET. In the NEUTRAL group, climate anger showed a strong positive association with the proportion of pro-environmental choices, whereas results for other ICE subscales were not

significantly correlated with PEB. This pattern is consistent with the broader argument that climate anger is especially morally laden and strongly activating. In the qualitative material from Study 1, anger emerged as one of the most salient responses to climate change, especially among people involved in sustained climate activism (Zaremba et al., 2022). It is also consistent with more recent quantitative work showing that climate anger is more strongly linked to engagement than several other climate emotions, including longitudinal evidence that it predicts subsequent pro-environmental intentions and behaviours over time better than anxiety or sadness (Contreras et al., 2023; Gregersen et al., 2023, 2025; Stanley et al., 2021). In the present study, trait climate anger may have functioned as a baseline motivational disposition, increasing the subjective value or moral priority of pro-environmental choices.

However, this behavioural association was not reflected by significant differences in brain activation in Hypothesis 11 (not supported). A likely explanation is limited statistical power. This analysis was restricted to the NEUTRAL group and tested individual differences in brain activity, where effects are often small and variable across participants (Gratton et al. 2022). Therefore, the study may not have had sufficient sensitivity to detect neural correlates of baseline climate anger, even though its behavioural association with PEB was observed.

9.4.6. Theoretical and methodological contributions

Study 4 makes several important contributions to environmental neuroscience. First, it contributes to the level of theoretical framing. Operationalising climate emotions with their appraisal structures and linking them to distributed brain systems is aligned with current trends in affective neuroscience (Mohammadi et al., 2023).

Regarding methodological contributions, the study demonstrates the feasibility of using validated, appraisal-informed ECCS stimuli in the scanner. ECCS provide a meaningful alternative to decontextualised emotional stimuli. This is an important advance, because existing climate-stimulus databases have focused on standardising climate-related imagery in terms of dimensional characteristics, such as relevance, valence, and arousal, or on identifying principles for effective public communication, rather than on manipulating explicitly defined appraisal patterns (Chapman et al., 2016; Lehman et al., 2019; Magalhães et al., 2018). By contrast, ECCS were developed from qualitative material and

designed to embed climate change within realistic social and moral contexts, thereby enabling the evocation of emotions through theoretically specified appraisal structures. This is especially useful in neuroimaging research, where narrative stimuli offer a favourable balance between ecological validity and experimental control (Jääskeläinen et al., 2021; Zak, 2015).

The study also adapted the Carbon Emission Task for fMRI as a consequential and quantifiable measure of pro-environmental behaviour. The task was adjusted to the scanner context by reducing visual complexity, introducing dummy trials to control for motor responding, and using a jittered event-related design. At the same time, it retained real consequences, as participants made decisions involving actual financial bonuses and real carbon offsets. This is an important methodological step, because it moves beyond hypothetical declarations and allows climate-relevant choice to be studied in a neuroimaging setting with meaningful incentives.

9.4.7. Limitations and future directions

Several limitations should be considered, but each also points to a clear direction for future research. First, the sample consisted of young Polish adults with moderate climate concern. This limits demographic and cultural generalisability, but it also makes the study theoretically and socially relevant. Young adults will live with the long-term consequences of climate change (Thiery et al., 2021), and moderately concerned individuals represent an important group for understanding when climate emotions may or may not translate into action (Kantar Polska, 2024). Future studies should test whether the present findings generalise to older adults, more diverse cultural contexts, and groups with low or very high climate concern.

Second, to keep the between-group design in the study sufficiently powered, the study focused only on two climate emotions - anger and hope. Investigation of these emotions is theoretically well justified (Geiger et al., 2023; Gregersen et al., 2023), but they represent only part of the broader climate-emotion landscape (Pihkala, 2022). Other emotions that are likely relevant for climate-related behaviour, such as guilt, anxiety, and compassion, were not examined at the level of brain activity, and could become the focus of future research.

Third, the Carbon Emission Task captures one specific type of PEB, namely a monetary trade-off between personal gain and climate benefit. Although this is a meaningful and consequential behavioural index, it does not necessarily generalise to other forms of climate action, such as habitual lifestyle behaviours, collective action, or decisions made in explicitly social contexts.

The findings of this study provide directions for future research on this topic. In this study, appraisal processes were inferred from the theoretically guided stimulus design, subjective emotion ratings, and prior evidence on appraisal-related brain correlates, rather than explicitly measured during the RRES or CET (Mohammadi et al., 2023; Sander et al., 2005; K. Scherer & Moors, 2019). This limits the precision with which specific appraisal profiles can be linked to later brain activity and behaviour. It remains possible that the manipulation induced heterogeneous appraisal profiles across participants, or that the appraisal dimensions most relevant for decision-making were not sufficiently aligned with the CET decision context to produce measurable effects. Future studies could therefore include trial-level appraisal ratings to test which appraisals are actually induced and whether they align with the subsequent decision context (Mohammadi et al., 2023). This issue applies to the broader research programme and is discussed further in the General Discussion.

10. General discussion

The overarching aim of this dissertation was to deepen the understanding of climate emotions, their appraisal structure, their links to PEB, and their brain mechanisms. To address this aim, the thesis followed a multi-method programme that moved from qualitative exploration, through stimulus development and behavioural experimentation, to neuroimaging. This sequence made it possible to examine the problem at several levels: lived experience, experimental manipulation, overt behaviour, and brain activity.

10.1. Conceptualisation of climate emotions

Study 1 demonstrated that emotions related to climate change are embedded in evaluations of relevance, causality, implications, coping potential and normative significance. Emotional responses to climate change often co-occur, shift over time, and exhibit ambivalence. This finding is consistent with constructivist approaches to emotion, in which emotional episodes are shaped by context, prior experience, social meaning, and personal goals. It also helps explain why climate emotions are difficult to study as simple, discrete categories. Participants described climate emotions in relation to perceived threat, responsibility, agency, coping potential, and social norms. These findings support the usefulness of the Component Process Model as a framework for organising climate emotions (Sander et al., 2018).

Study 2 translated qualitative findings into the Emotional Climate Change Stories, a standardised and empirically grounded stimulus set that enabled elicitation of climate emotions with greater precision than decontextualised images or generic messages (Briesemeister et al., 2014; Harmon-Jones et al., 2017). Although this stimulus format was chosen to specify appraisals more precisely, the stories still elicited affective responses resembling everyday emotional experience, where emotions often co-occur and do not map neatly onto single categories. Anxiety stories often elicited compassion, anger, and guilt, while guilt stories were relatively difficult to evoke strongly and specifically. This pattern is consistent with an appraisal-based account of climate emotions, suggesting that the same story content may activate overlapping appraisals and therefore elicit blends of emotions

rather than one discrete emotional state. Climate anxiety may often include concern for victims, anticipation of harm, and helplessness. Climate guilt may require stronger self-relevance and identification than third-person narratives provide, and may also activate defensive responses aimed at protecting moral self-image (Caillaud et al., 2016; Ma & Hmielowski, 2022). In contrast, anger, compassion and hope stories elicited relatively distinct emotions.

Together, Studies 1 and 2 show that climate emotions can be decomposed into appraisal patterns, but that these patterns partly overlap. This has practical implications for experimental design. Stimuli intended to elicit climate emotions should not be selected only on the basis of emotion labels, valence, or arousal. They should also be evaluated in terms of the appraisal structures they contain, including agency, responsibility, coping potential, and normative meaning.

10.2. From emotion to climate action

Another contribution of the thesis concerns the effects of induced climate emotions. Studies 3 and 4 tested whether climate anger, compassion, and hope could increase consequential PEB. Across two well-powered, methodologically strong studies, brief, incidental inductions of climate emotions were effective at the subjective level, but did not increase PEB. In Study 3, induced anger, compassion, and hope did not increase effort in the Work for Environmental Protection Task, monetary donations, or preferences for emotion-specific donation aims. In Study 4, induced anger and hope did not increase pro-environmental choices in the Carbon Emission Task, nor did they modulate decision-related brain activity.

Studies differed in several design features that could, in principle, have affected sensitivity to emotion manipulation. Because this pattern appeared across different samples, settings, exposure formats, and behavioural measures, the result is unlikely to be specific to one task. It instead points to limited carryover from incidental emotion induction to consequential PEB, that can be explained by several mechanisms. First, the induced emotions may have been too brief or insufficiently sustained. Second, affect labelling and cognitive load may have reduced the persistence of the induced emotional state (Lieberman et al., 2007; Van Dillen et al., 2009). Third, decisions involving donations, effort, or monetary trade-offs against carbon reduction may evoke their own integral affect,

including guilt, conflict, moral satisfaction, or “warm glow” (Berger & Wyss, 2021; FeldmanHall & Heffner, 2022; Shipley & van Riper, 2022). Such task-generated affect may attenuate any effects of incidental emotions induced earlier. Finally, the action tendencies elicited by the stories may not have been matched to the type of PEB operationalized by the experimental tasks.

The neuroimaging results add another layer to this conclusion. Climate emotions recruited distributed brain regions consistent with appraisal-based processing, including regions related to salience, social meaning, self-referential evaluation, and future-oriented thought. At the same time, climate-relevant decisions in the Carbon Emission Task engaged valuation and control-related regions, but these activation patterns were not modulated by prior emotion induction. This convergence between behavioural and brain null effects strengthens the interpretation that the central issue was the limited carry-over of elicited emotions into PEB.

10.3. The potential of baseline climate emotions

The finding that baseline climate anger was positively associated with PEB further suggests that baseline climate emotions may be more relevant for behaviour than transient affective states. This finding is consistent with the qualitative results of Study 1, where anger was described as action-oriented when directed at identifiable responsible agents, such as political leaders, corporations, or institutions. It is also consistent with longitudinal and correlational research showing that climate anger is linked to engagement and may predict pro-environmental intentions and behaviour more consistently than some other climate emotions, such as anxiety or sadness (Contreras et al., 2024; Gregersen et al., 2023, 2025; Stanley et al., 2021). Climate anger may reflect a more stable moral and motivational orientation, in which climate harm is appraised as unjust, responsibility is attributed to identifiable agents, and action is seen as necessary or normatively justified (Bright & Eames, 2021).

This distinction also helps reconcile apparently inconsistent findings in the field. Climate emotions may be strong correlates of engagement when they reflect enduring appraisals, values, identity, and coping strategies. At the same time, briefly eliciting a similar emotion in the laboratory may not reproduce this motivational structure. Future research should

clearly distinguish among state emotions, baseline emotional dispositions, and repeated emotional experiences over time. This distinction is particularly important in climate change research, where emotions are often not isolated episodes but persistent responses to an issue that people encounter repeatedly in the media, public debate, and everyday life (Heeren & Clayton, 2026; Pihkala, 2022).

10.4. Practical and methodological contributions

The methodological contribution of the dissertation lies in linking three elements that are often studied separately: an empirically grounded map of climate emotions and the related appraisals, validated narrative stimuli for their induction, and consequential behavioural tasks suitable for experimental and fMRI contexts. The tools developed and applied in this dissertation offer valuable resources for future research. Since its publication, ECCS have already been tested and included as an effective manipulation in a mega-study on determinants of climate advocacy in a large US sample (Goldwert et al., 2026). The adapted, scanner-compatible CET task can be reused by researchers interested in measuring PEB beyond self-reported intentions. Because it captures actual climate-relevant choices, it helps to address long-standing concerns about ecological validity in climate action research (Dablander et al., 2025; Sinclair et al., 2025).

Environmental neuroscience is a young discipline that requires robust methodological frameworks and more data to advance (Doell et al., 2023). As a resource-intensive endeavour, it is also responsible for adopting practices that align with climate goals, such as reducing GHG emissions. Nearly every stage of neuroimaging research - planning, data collection, preprocessing, analysis and storage - can be optimised in terms of its carbon footprint (Souter et al., 2023). Open-science practice of public storage of data and analytic code can align with climate goals, especially if science is FAIR - findable, accessible, interoperable, and reusable (Wilkinson et al., 2016). Open access to collected data prevents researchers from duplicating work and promotes greater reuse of resources. These reflections guided the decision to publicly share the complete data and materials from the present research, in the form of data and code repositories, as well as open-access articles. The public release of the CLIMATE BRAIN dataset is itself an important contribution of the dissertation, as it provides a reusable multimodal resource for future work on climate

emotions and climate-related decision-making while reducing the need to duplicate resource-intensive neuroimaging data collection (Zaremba, Kossowski, et al., 2025).

10.5. Limitations and future research

Some limitations should be considered at the research programme level. First, although the thesis adopted an appraisal-based framework, appraisals were not measured directly at the trial level. Instead, they were inferred from qualitative content, stimulus design, subjective emotion ratings, and previous evidence linking cognitive processes to brain activity. This limits the extent to which specific appraisals, such as responsibility, personal relevance, coping potential, future consequences, and normative significance, can be linked to the observed behaviour and brain activity. Future studies should ask participants to rate these appraisals directly after each stimulus, and where relevant after each decision (Mohammadi et al., 2023). This would allow us to conduct a within-person analysis of which appraisal profiles were actually induced and whether they explain later PEB.

Future research should also move toward more personalised climate messaging. Climate narratives may be more effective when they are matched to participants' prior values, concerns, and motivational orientations (Corner, 2016). The present research programme treated emotion categories as universally defined conditions, but the same story may not be equally relevant or persuasive for all individuals. Instead, a narrative may elicit anger, compassion, or hope only when it activates values and concerns that are personally relevant to the recipient (Joyal-Desmarais et al., 2022; Sabherwal & Shreedhar, 2022). This suggests that climate communication could be improved by selecting or adapting narratives to fit individual appraisal profiles, rather than relying on a single universally persuasive framing. This idea is consistent with recent evidence that responses to energy transition narratives vary as a function of personal value alignment rather than reflecting a single universally persuasive frame (Lammers et al., 2026).

The experimental inductions in this line of research were brief and presented before, rather than within, the behavioural tasks. This was appropriate for experimental control, but may not capture how climate emotions operate in everyday life, where they often recur over time and become linked to values, identity, social identity, and coping strategies (Berger & Bregulla, 2023; Ojala et al., 2021; Steg & Vlek, 2009). Useful models can be found in

household energy and water conservation studies, where researchers have tracked objective behavioural outcomes across repeated observations and tested whether intervention effects persist, decay, or become habitual (Allcott & Rogers, 2014). A related limitation is that the PEB measurement is not affectively neutral. Behavioural tasks may generate their own integral affect, such as guilt, conflict, moral satisfaction, or “warm glow”, which could reduce the influence of emotions induced a few moments earlier (FeldmanHall & Heffner, 2022; Västfjäll et al., 2016). Future work should therefore test repeated, longitudinal, and ecological momentary designs, as well as designs in which emotional appraisals are embedded directly in the decision context rather than presented only beforehand.

A further direction for future research is to extend the range of climate emotions. The present studies necessarily focused on selected emotions, chosen for theoretical and empirical reasons. This focus allowed a more controlled test of specific emotion categories and helped preserve interpretability, especially in the fMRI study, where Study 4 was limited to anger and hope to maintain statistical power. At the same time, Studies 2 and 3 showed that other climate emotions also deserve investigation. Anxiety and guilt were relatively difficult to evoke strongly and specifically with third-person narratives, while compassion and anger partly overlapped in participants’ experience. Future studies should therefore examine other emotions such as guilt, anxiety, compassion, enthusiasm, and powerlessness using stimulus formats that increase self-relevance, identification, and direct measurement of context-specific appraisals.

Future research could also examine a wider range of climate-relevant behaviours. Present studies used a wide range of tasks: WEPT measured time and cognitive effort, the donation task measured monetary giving, and CET measured repeated trade-offs between personal financial gain and carbon reduction. These tasks provided consequential and quantifiable outcomes, but climate action includes many other behaviours, including collective action, voting, public communication, lifestyle change, and support for structural climate policy (Lange & Dewitte, 2019). Future studies should match emotional appraisals closely with the specific behavioural demands of the task. Anger may be more likely to motivate protest or collective action, while hope may be more relevant for policy support or endorsement for promising technological solutions.

A final direction for future research is to test the generalisability of these findings across broader samples and more naturalistic contexts. The present programme combined different levels of control and ecological breadth. Study 3 used large samples from Poland and Norway, which allowed cross-national behavioural testing, whereas Study 4 used a more homogeneous sample of young adults from Poland with moderate climate concern. This narrower sample was appropriate for fMRI research, where reducing heterogeneity can improve interpretability and statistical control. Future research should test whether the present findings generalise across age groups, cultures, levels of climate concern, and real-world action contexts. Such work would help clarify when climate emotions remain ineffective, and when they become stable motivational orientations that support sustained climate action.

11. General summary and conclusions

The dissertation contributes a coherent and methodologically rigorous line of research. It sets out to examine how climate emotions are constructed, how they can be studied experimentally, and whether they translate into PEB and climate-relevant decision-making. In a unique multi-method research programme, it combined qualitative interviews, stimulus development and validation, large-scale behavioural experiments, a scanner-compatible experimental tasks, and state-of-the-art neuroimaging methods. This design allowed climate emotions to be examined at several levels: as lived and narrated experiences, as experimentally induced states, as self-reported responses, as predictors of consequential behaviour, and as patterns of brain activity.

The first contribution of the dissertation is theoretical. The findings support an appraisal-based understanding of climate emotions (Brosch, 2021). Climate emotions are shaped by appraisals of what is at stake, who or what is responsible, what consequences may follow, whether action is possible, and whether the situation violates personally or socially important values. This perspective helps explain why climate emotions often overlap, why the same event may elicit different responses in different people, and why their relationship with behaviour is likely to depend on personal meaning and context.

The second contribution is methodological. The dissertation developed and applied tools that can be reused in future research, including the Emotional Climate Change Stories

(Zaremba et al., 2024), a behavioural and neuroimaging CLIMATE BRAIN database (Zaremba, Kossowski, et al., 2025), and an adapted, scanner-compatible version of the Carbon Emission Task (Berger & Wyss, 2021). It also tested climate emotions in large samples and in a carefully controlled neuroimaging setting. Importantly, the programme did not rely only on self-reported intentions, but included consequential behavioural measures, repeated trade-offs, and brain activity during both emotion elicitation and decision-making (Dablander et al., 2025). Together with conservative analytic choices and open-science practices, this makes the dissertation a strong methodological contribution to environmental neuroscience.

The third contribution is empirical. Across studies, climate emotions were successfully elicited at the subjective level. In the fMRI study, climate anger and hope also recruited brain regions consistent with appraisal-related processing during story reading, including regions implicated in relevance detection, social meaning, self-referential evaluation, and future-oriented thought. Climate-relevant decisions engaged regions associated with valuation and cognitive control (ref). However, brief emotion induction did not increase PEB and did not lead to significant differences in decision-related brain activity. This pattern is important because it challenges an overly simplified and optimistic view of emotions as direct levers of behaviour change (Chapman et al., 2017). The findings show that making people feel anger, hope, or compassion for a short time is not necessarily sufficient to change consequential climate-related choices.

This dissertation clarifies when and how the motivational role of climate emotions may be limited. The behavioural association between baseline climate anger and PEB suggests that more stable climate emotions may matter more than transient emotional states induced immediately before a task. This points to a distinction between momentary affect and more enduring emotional appraisals that are integrated with values, responsibility, identity, and expectations about the future. In this sense, the null effects sharpen the theory by showing that the link between emotion and action is conditional and probably stronger when emotions are sustained, personally meaningful, and connected to available forms of action.

This conclusion has practical implications for climate communication and intervention design. Anger, hope, compassion, guilt, or anxiety may become motivationally relevant when they are embedded in narratives, social identities, repeated experiences, and concrete

opportunities to act. Future research should therefore move beyond one-off emotion induction and test repeated, longitudinal, and more personalised designs in which emotional appraisals are measured directly and integrated with the decision context itself.

Overall, this dissertation argues for a more demanding and more realistic science of climate emotions. It shows that climate emotions can be elicited, measured, mapped in the brain, and related to behaviour, but it also shows that they should not be treated as simple levers that automatically produce climate action. Their motivational value lies in the appraisals and meanings through which people understand the climate crisis, their own responsibility, and the possibility of change. The central take-home message is therefore that climate emotions matter for action not merely when they are briefly triggered, but when they become a part of persons' habits, values and identity. Under such conditions, the motivational role of climate emotions may become more pronounced, more stable, and more informative for both theory and practice.

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- Zaremba, D.**, Marczak, M., Michałowski J., Klöckner, C.A., Wierzba, M., Marchewka, A. (2026). Impact of anger, compassion, and hope on climate action taking. Scientific Reports. In production. doi:[10.1038/s41598-026-56796-9](https://doi.org/10.1038/s41598-026-56796-9).
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- Zaremba, D.**, Kulesza, M., Herman, A. M., Marczak, M., Kossowski, B., Budziszewska, M., ... & Wierzba, M. (2023). A wise person plants a tree a day before the end of the world: coping with the emotional experience of climate change in Poland. *Current Psychology*, 42(31), 27167-27185. doi.org/[10.1007/s12144-022-03807-3](https://doi.org/10.1007/s12144-022-03807-3)
- Herman, A. M., **Zaremba, D.**, Kossowski, B., & Marchewka, A. (2022). The utility of the emBODY tool as a novel method of studying complex phenomena-related emotions. *Scientific Reports*, 12(1), 19884. doi.org/[10.1038/s41598-022-23734-4](https://doi.org/10.1038/s41598-022-23734-4)
- Marczak, M., Wierzba, M., **Zaremba, D.**, Kulesza, M., Szczypiński, J., Kossowski, B., Budziszewska, M., Michałowski, J. M., Klöckner, C. A., & Marchewka, A. (2023). Beyond climate anxiety: Development and validation of the inventory of climate emotions (ICE): A measure of multiple emotions experienced in relation to climate change. *Global Environmental Change: Human and Policy Dimensions*, 83, 102764. doi.org/[10.1016/j.gloenvcha.2023.102764](https://doi.org/10.1016/j.gloenvcha.2023.102764)

14. Supplementary materials

Table S1. Demographic composition of the sample in Study 1.

Demographic variables	Sample (N = 40)	
Age	Men	Women
Generation Z (M = 21.00, SD = 1.73, range 18-24 y.o.)	6	5
Millennials (M = 32.71, SD = 4.82, range 25-40 y.o.)	9	8
Generation X (M = 49.67, SD = 3.88, range 42-53 y.o.)	2	4
Baby Boomer (M = 65.60, SD = 3.65, range 61-70 y.o.)	2	3
Silent Generation (M = 82, SD n/a, range n/a)	-	1
Place of residence		
Urban (over 500 000 inhabitants)	55 %	
Urban (from 100 000 to 500 000 inhabitants)	15 %	
Urban (up to 100 000 inhabitants)	15 %	
Rural	15 %	
Education		
Primary	2,5 %	
Secondary	55 %	
Higher	42,5 %	
Parenthood status		
No children	57,5 %	
Children	42,5 %	
Environmental engagement		
Employment related to climate change *	32,5 %	
Climate activists	25 %	
None of the above	42,5 %	

* e.g. researcher, NGO, public services, or private sector related to climate change or environmental protection

Table S2. Demographic composition of the sample in Study 2.

Demographic variables	Sample 1 - Poland (N=601)	Sample 2 - Poland (N = 307)	Sample 3 - Norway (N = 346)
Gender	504 F, 92 M, 5 other	164 F, 142 M, 1 other	181 F, 165 M
Age (mean, range)	M = 26.26 (18-62)	M = 39.09 (18-73)	M = 45.57 (18-85)
Place of residence			
Rural	11%	25%	5%
Urban under 50 000	13%	25%	45%
Urban over 50 000 - 100 000	9%	14%	24%
Urban over 100 000	66%	36%	25%
Education			
Primary	0.5%	11%	8%
Secondary	59%	62%	45%
Higher	41%	26%	48%
Belief in climate change: Climate change...			
... is definitely happening	83%	59%	53%
... is likely happening	14%	36%	41%
... is likely not happening	1%	4%	6%
... is definitely not happening	2%	<1%	<1%
Concern about climate change			
High	25%	32%	28%
Medium	44%	35%	36%
Low	29%	32%	36%
Other factors influencing climate change attitudes			
Is a parent	16%	56%	62%
Employment related to climate change *	7%	10%	27%
Climate activists	6%	11%	35%

* e.g. researcher, NGO, public services, or private sector related to climate change or environmental protection

Table S3. Demographic composition of the Polish sample in Study 3.

Demographic variables	NEUTRAL (N = 260)	ANGER (N = 257)	COMPASSION (N = 261)	HOPE (N = 251)
Gender	140 F, 120 M	131 F, 126 M	120 F, 141 M	128 F, 122 M, 1 other
Is a parent	173 (67%)	162 (63%)	178 (68%)	166 (66%)
Generation				
Z	34 (13%)	38 (15%)	29 (11%)	35 (14%)
Y	78 (30%)	85 (33%)	92 (35%)	90 (36%)
X	78 (30%)	69 (27%)	73 (28%)	62 (25%)
Boomer	69 (27%)	64 (25%)	67 (26%)	61 (24%)
Silent	1 (0.4%)	1 (0.4%)	0 (0%)	3 (1.2%)
Place of residence				
Big city	99 (38%)	91 (35%)	104 (40%)	88 (35%)
Suburbs of a big city	24 (9.2%)	22 (8.6%)	14 (5.4%)	26 (10%)
Small city	82 (32%)	80 (31%)	91 (35%)	72 (29%)
Country village	55 (21%)	64 (25%)	52 (20%)	65 (26%)
Education				
Primary	10 (3.8%)	11 (4.3%)	8 (3.1%)	6 (2.4%)
Secondary	160 (61.5%)	170 (66.1%)	170 (65.1%)	172 (68.5%)
University/College	90 (35%)	76 (30%)	83 (32%)	73 (29%)
Socio-economic status				
Living comfortably on present income	28 (11%)	22 (8.6%)	25 (9.6%)	25 (10.0%)
Coping on present income	155 (60%)	166 (65%)	158 (61%)	169 (67%)
Difficult on present income	72 (28%)	64 (25%)	69 (26%)	53 (21%)
Very difficult on present income	5 (1.9%)	5 (1.9%)	9 (3.4%)	4 (1.6%)
Belief in climate change: Climate change...				
... is definitely happening	161 (62%)	163 (63%)	155 (59%)	147 (59%)
... is likely happening	82 (32%)	83 (32%)	98 (38%)	91 (36%)
... is likely not happening	14 (5.4%)	11 (4.3%)	7 (2.7%)	13 (5.2%)

... is definitely not happening	3 (1.2%)	0 (0%)	1 (0.4%)	0 (0%)
Concern about climate change				
Not at all concerned	8 (3.1%)	7 (2.7%)	9 (3.5%)	8 (3.2%)
A little concerned	10 (3.9%)	9 (3.5%)	13 (5.0%)	22 (8.8%)
Somewhat concerned	58 (23%)	58 (23%)	54 (21%)	52 (21%)
Very concerned	109 (42%)	94 (37%)	95 (37%)	87 (35%)
Extremely concerned	72 (28%)	89 (35%)	89 (34%)	82 (33%)
PCAE - total*	11.73 (3.59)	12.07 (3.33)	11.54 (3.67)	11.71 (3.84)
PCAE - personal*	5.40 (2.03)	5.59 (1.93)	5.39 (1.98)	5.48 (2.09)
PCAE - collective*	6.33 (1.88)	6.48 (1.73)	6.15 (1.96)	6.23 (2.02)
PD*	7.32 (2.10)	7.25 (2.03)	7.33 (2.33)	7.02 (2.19)
WTS*	26.98 (8.75)	28.00 (8.31)	26.63 (9.23)	26.78 (9.09)

*Mean and SD values presented for the following variables: PCAE (personal and collective climate action efficacy), PD (psychological distance) and WTS (willingness to sacrifice for the environment).

Table S4. Demographic composition of the Norwegian sample in Study 3.

Demographic variables	NEUTRAL (N = 244)	ANGER (N = 256)	COMPASSION (N = 255)	HOPE (N = 255)
Gender	125 F, 119 M	124 F, 129 M, 3 other	125 F, 129 M, 1 other	125 F, 130 M
Is a parent	143 (59%)	163 (64%)	156 (61%)	159 (62%)
Generation				
Z	36 (15%)	42 (16%)	53 (21%)	27 (11%)
Y	70 (29%)	71 (28%)	69 (27%)	71 (28%)
X	72 (30%)	67 (26%)	59 (23%)	76 (30%)
Boomer	61 (25%)	75 (29%)	72 (28%)	78 (31%)
Silent	5 (2.0%)	1 (0.4%)	2 (0.8%)	3 (1.2%)
Place of residence				
Big city	67 (27%)	82 (32%)	68 (27%)	63 (25%)
Suburbs of a big city	45 (18%)	45 (18%)	55 (22%)	47 (18%)
Small city	76 (31%)	78 (30%)	77 (30%)	73 (29%)
Country village	56 (23%)	51 (20%)	55 (22%)	72 (28%)
Education				

Primary	25 (10%)	15 (5.9%)	30 (12%)	23 (9.0%)
Secondary	116 (48%)	116 (45%)	109 (43%)	122 (48%)
University/College	100 (41%)	124 (48%)	115 (45%)	107 (42%)
Socio-economic status				
Living comfortably on present income	80 (33%)	83 (32%)	88 (35%)	60 (24%)
Coping on present income	96 (39%)	105 (41%)	108 (42%)	104 (41%)
Difficult on present income	54 (22%)	52 (20%)	43 (17%)	73 (29%)
Very difficult on present income	14 (5.7%)	16 (6.3%)	16 (6.3%)	18 (7.1%)
Belief in climate change: Climate change...				
... is definitely happening	118 (48%)	122 (48%)	131 (51%)	125 (49%)
... is likely happening	108 (44%)	115 (45%)	102 (40%)	110 (43%)
... is likely not happening	15 (6.1%)	17 (6.6%)	20 (7.8%)	15 (5.9%)
... is definitely not happening	3 (1.2%)	2 (0.8%)	2 (0.8%)	5 (2.0%)
Concern about climate change				
Not at all concerned	14 (5.8%)	11 (4.3%)	11 (4.3%)	15 (6.0%)
A little concerned	17 (7.1%)	19 (7.5%)	25 (9.9%)	23 (9.2%)
Somewhat concerned	56 (23%)	73 (29%)	54 (21%)	67 (27%)
Very concerned	97 (40%)	94 (37%)	93 (37%)	94 (38%)
Extremely concerned	57 (24%)	57 (22%)	70 (28%)	51 (20%)
PCAE - total*	10.83 (3.71)	10.76 (3.52)	10.41 (3.73)	10.64 (3.74)
PCAE - personal*	4.97 (2.08)	5.00 (2.00)	4.79 (2.00)	4.87 (2.14)
PCAE - collective*	5.86 (1.97)	5.76 (1.87)	5.62 (2.03)	5.77 (1.95)
PD*	6.61 (2.32)	6.63 (2.13)	6.62 (2.39)	6.49 (2.22)
WTS*	25.23 (8.80)	24.75 (8.61)	25.11 (8.31)	24.57 (8.67)

*Mean and SD values presented for the following variables: PCAE (personal and collective climate action efficacy), PD (psychological distance) and WTS (willingness to sacrifice for the environment).

Table S5. Demographic composition of the sample in Study 4.

Demographic variables	ANGER (N = 54)	HOPE (N = 54)	NEUTRAL (N = 52)
Gender	27 F, 27 M	27 F, 27 M	26 F, 26 M
Age (mean, SD)	22.5 (SD = 1.77)	22.46 (SD = 2.01)	22.6 (SD = 1.51)
Place of residence			
Big city	42 (77.8%)	44 (81.5%)	47 (90.4%)
Suburbs of a big city	6 (11.1%)	4 (7.4%)	3 (5.8%)
Small city	3 (5.6%)	4 (7.4%)	1 (1.9%)
Country village	3 (5.6%)	2 (3.8%)	1 (1.9%)
Education			
Vocational	0 (0.0%)	1 (1.9%)	0 (0.0%)
Upper secondary	42 (77.8%)	40 (74.1%)	35 (67.3%)
Bachelor's or engineering degree	8 (14.8%)	9 (16.7%)	10 (19.2%)
Master's or medical degree	4 (7.4%)	4 (7.4%)	7 (13.5%)
Political orientation			
Has any political views	31 (57.4%)	38 (70.4%)	33 (63.5%)
Can describe the political views in terms of left-right orientation	27 (50.0%)	30 (55.6%)	27 (51.9%)
Political orientation (mean, SD)*	4.48 (SD = 2.72)	4.00 (SD = 2.77)	2.48 (SD = 2.23)
Car use (as a driver or passenger)			
Once or several times a year	13 (24.1%)	10 (18.5%)	10 (19.2%)
Once or several times a month	26 (48.1%)	19 (35.2%)	25 (48.1%)
Once or several times a week	15 (27.8%)	17 (31.5%)	13 (25.0%)
Every day	0 (0.0%)	8 (14.8%)	4 (7.7%)
Has a driver's license	28 (51.9%)	36 (66.7%)	37 (71.2%)
Socioeconomic status			
Comfortable on present income	15 (27.8%)	19 (35.2%)	15 (28.8%)

Coping on present income	31 (57.4%)	33 (61.1%)	36 (69.2%)
Difficult on present income	8 (14.8%)	2 (3.7%)	1 (1.9%)

*Political orientation scale from 0 - far left to 10 far right.

Table S6. Mapping of the macro-anatomical labels to the Neuromorphometrics atlas labels.

Macro-anatomical labels used in the text	Neuromorphometrics parcel
Amygdala	Amygdala_L.nii
	Amygdala_R.nii
TPJ/angular gyrus	Angular_L.nii
	Angular_R.nii
Anterior cingulate cortex (ACC)/ mid-cingulate cortex (MCC)	Cingulate_Ant_L.nii
	Cingulate_Ant_R.nii
	Cingulate_Mid_L.nii
	Cingulate_Mid_R.nii
Lateral orbitofrontal cortex (OFC)/ orbital IFG /Inferior frontal gyrus	Frontal_Inf_Orb_2_L.nii
	Frontal_Inf_Orb_2_R.nii
Middle frontal gyrus/Dorsolateral prefrontal cortex (DLPFC)	Frontal_Mid_2_L.nii
	Frontal_Mid_2_R.nii
Dorsomedial prefrontal cortex (DMPFC)/ Superior frontal cortex/ Medial frontal cortex	Frontal_Sup_Medial_L.nii
	Frontal_Sup_Medial_R.nii
Hippocampus	Hippocampus_L.nii
	Hippocampus_R.nii
Insula	Insula_L.nii
	Insula_R.nii
Nucleus accumbens/ventral striatum	N_Acc_L.nii
	N_Acc_R.nii
Posterior cingulate cortex (PCC)/Precuneus	Precuneus_L.nii
	Precuneus_R.nii
	Cingulate_Post_L.nii

	Cingulate_Post_R.nii
	Putamen_L.nii
	Putamen_R.nii
	Caudate_L.nii
Dorsal striatum/putamen/caudate	Caudate_R.nii
	Rectus_L.nii
	Rectus_R.nii
Ventrolateral prefrontal cortex (VMPFC)	Frontal_Med_Orb_L.nii
	Frontal_Med_Orb_R.nii
	Supp_Motor_Area_L.nii
Supplementary motor area / pre-SMA	Supp_Motor_Area_R.nii
	Temporal_Pole_L.nii
	Temporal_Pole_R.nii
	Temporal_Pole_Sup_L.nii
Temporal pole/Middle temporal gyrus /Middle temporal cortex	Temporal_Pole_Sup_R.nii

Table S7. Effect of emotional content (ANG + HOP > NEU). Second-level whole-brain results from the planned contrast (weights [0.5 0.5 -1]) in a one-way between-subjects ANOVA on the story-reading contrast images (TAR > CON), within the functionally defined story-processing mask, pFWE < .05, no extent threshold (k = 0). For each significant cluster, the following information is provided: peak T value, MNI coordinates and cluster extent in voxels. Anatomical labels assigned with Neuromorphometrics atlas; if a peak voxel was located outside labeled gray matter, the nearest gray matter structure was reported.

ANG + HOP > NEU		MNI coordinates			Extent
Region label	T	x	y	z	k
Left PCgG posterior cingulate gyrus	12.00	-4	-52	24	50
Left MTG middle temporal gyrus	11.41	-64	-14	-16	660
	9.63	-61	-7	-26	
Left TMP temporal pole	7.49	-51	8	-33	

Right MFC medial frontal cortex	10.76	2	36	-20	378
Left MFC medial frontal cortex	7.51	-4	56	-13	
Left AnG angular gyrus	10.52	-46	-67	40	229
Left SFG superior frontal gyrus	10.21	-16	36	50	579
	7.88	-11	46	37	
	7.52	-14	58	24	
Right MTG middle temporal gyrus	9.50	64	-7	-20	70
Right Cerebellum Exterior	8.27	4	-57	-48	101
Left Caudate	8.07	-11	8	17	69
Right Cerebellum Exterior	7.76	42	-72	-36	240
	6.75	14	-87	-33	
	6.50	22	-82	-28	
Right Caudate	7.37	9	10	12	33
Left PCu precuneus	6.98	-11	-47	37	3
Right TMP temporal pole	6.46	42	18	-33	14
Left Cerebellum Exterior	5.52	-34	-80	-33	4
Left Pallidum	5.26	-16	3	-3	2
Right MSFG superior frontal gyrus medial segment	5.25	6	56	30	4
Left Hippocampus	5.24	-31	-14	-16	17
Left Hippocampus	5.12	-31	-30	-10	2
Right Hippocampus	5.11	29	-14	-20	28
Left MFG middle frontal gyrus	5.03	-38	16	52	19

Right Ventral DC	5.00	6	-7	-10	1
Right Caudate	4.66	9	6	0	2
Left Ventral DC	4.54	-6	-20	-18	1

Table S8. Second-level whole-brain results from the planned contrast ANG > HOP in the one-way between-subjects ANOVA on TAR > CON contrast images, within the functionally defined story-processing mask, pFWE < .05, no extent threshold (k = 0). For each significant cluster, the following information is provided: peak T value, MNI coordinates and cluster extent in voxels.

ANG > HOP		MNI coordinates			Extent
Region label	T	x	y	z	k
Right Caudate	5.42	9	10	12	14
Left Caudate	5.32	-14	6	14	24

Table S9. Second-level whole-brain results from the planned contrast HOP > ANG in the one-way between-subjects ANOVA on TAR > CON contrast images, within the functionally defined story-processing mask, pFWE < .05, no extent threshold (k = 0). For each significant cluster, the following information is provided: peak T value, MNI coordinates and cluster extent in voxels.

HOP > ANG		MNI coordinates			Extent
Region label	T	x	y	z	k
Left OCP occipital pole	5.15	-6	-102	4	12
Right OCP occipital pole	4.82	14	-97	10	10

Table S10. Second-level whole-brain results for the planned contrast CET > dummy. Individual CET > dummy contrast images were entered into a one-sample t-test, pFWE < .05, no extent threshold (k = 0). For each significant cluster, the following information is provided: peak T value, MNI coordinates and cluster extent in voxels. Anatomical labels assigned with Neuromorphometrics atlas; if a peak voxel was located outside labeled gray matter, the nearest gray matter structure was reported.

CET>dummy		MNI coordinates			Extent
Region label	T	x	y	z	k
Left MSFG superior frontal gyrus medial segment	13.34	-6	26	37	2908
Left Caudate	12.29	-11	16	-3	
Right Caudate	9.99	12	16	0	
Left AIns anterior insula	10.71	-38	10	-10	512
Left POrG posterior orbital gyrus	10.38	-26	26	-18	
Left LOrG lateral orbital gyrus	9.60	-36	33	-13	
Left PCgG posterior cingulate gyrus	9.88	-6	-52	22	425
	7.17	-14	-50	7	
Right PCgG posterior cingulate gyrus	6.98	14	-44	4	
Right MFG middle frontal gyrus	9.81	46	40	14	174
Right MORG medial orbital gyrus	8.01	24	30	-18	226
Right LOrG lateral orbital gyrus	7.64	34	38	-10	
Right AIns anterior insula	7.14	39	16	-10	
Right PHG parahippocampal gyrus	7.65	24	-22	-18	118
	6.93	19	-12	-26	
Right Hippocampus	6.87	26	-14	-23	
Left Hippocampus	7.44	-24	-17	-18	71
Right SFG superior frontal gyrus	7.26	19	33	50	105

Left PCgG posterior cingulate gyrus	6.53	-1	-34	34	27
Left TrIFG triangular part of the inferior frontal gyrus	6.34	-51	36	17	24
Brain Stem	5.99	2	-32	-20	26
Right Ventral DC	5.90	4	-24	0	
Brain Stem	5.43	6	-27	-8	
Left Calc calcarine cortex	5.95	-8	-90	-8	7
Left Thalamus Proper	5.72	-4	-10	2	3
Right IOG inferior occipital gyrus	5.70	49	-77	-3	21
Right Cerebellum Exterior	5.44	44	-62	-43	8
Left Ventral DC	5.26	-14	-12	-16	2
Left MTG middle temporal gyrus	5.25	-64	-12	-18	1
Left Hippocampus	5.22	-14	-37	7	1
Right TMP temporal pole	5.12	39	10	-33	1
Right Hippocampus	5.07	32	-30	-10	1
Left Ventral DC	5.03	-4	-22	0	1
Right TMP temporal pole	4.99	36	18	-30	2
Left TMP temporal pole	4.98	-41	10	-33	1
Right Thalamus Proper	4.93	4	-10	2	1

Table S11. Second-level results for the planned contrast PEB > SIB. Individual PEB > SIB contrast images were entered into a one-sample t-test, pFWE < .05, no extent threshold ($k = 0$), restricted to a functionally defined climate decision mask. For each significant cluster, the following information is provided: peak T value, MNI coordinates and cluster extent in voxels. Anatomical labels assigned with Neuromorphometrics atlas; if a peak voxel was located outside labeled gray matter, the nearest gray matter structure was reported.

PEB > SIB		MNI coordinates			Extent
Region label	T	x	y	z	k
Left OFuG occipital fusiform gyrus	5.35	-16	-84	-10	12
Right MFG middle frontal gyrus	4.81	49	38	24	6
Left Cerebellum Exterior	4.67	-41	-67	-43	2

Table S12. Second-level results for the planned contrast SIB > PEB. Individual SIB > PEB contrast images were entered into a one-sample t-test, FWE < .05, no extent threshold ($k = 0$), restricted to a functionally defined climate decision mask. For each significant cluster, the following information is provided: peak T value, MNI coordinates and cluster extent in voxels. Anatomical labels assigned with Neuromorphometrics atlas; if a peak voxel was located outside labeled gray matter, the nearest gray matter structure was reported.

SIB > PEB		MNI coordinates			Extent
Region label	T	x	y	z	k
Left ACgG anterior cingulate gyrus	6.22	-6	23	-6	119
Left Accumbens Area	5.35	-8	6	-6	
Right Accumbens Area	5.05	4	13	-3	
Left ACgG anterior cingulate gyrus	5.07	-1	40	0	20
Left MFC medial frontal cortex	4.67	-8	53	-10	3
Left Hippocampus	4.38	-28	-32	-10	1