Threat and Anxiety in the Climate Debate: *An Agent-Based Model to investigate Climate Scepticism and Pro-Environmental Behaviour*

Marie Lisa Kapeller and Georg Jäger

Institute of Systems Sciences, Innovation and Sustainability Research, University of Graz, Austria

Author Note

Correspondence concerning this article should be addressed to M. L. Kapeller, Institute of Systems Sciences, Innovation and Sustainability Research, University of Graz, 8010 Graz, Austria. E-mail: marie.kapeller@uni-graz.at

Abstract

How people react to threatening information such as climate change is a complicated matter. While people with a high environmental self-identity tend to react approach-motivated by engaging in pro-environmental behaviour, people of low environmental self-identity may exhibit proximal defence behaviour, by avoiding and distracting themselves from potentially threatening stimuli caused by identified anxious thoughts and circumstances. This psychological theory has recently been tested in experimental studies in which the results suggest that the promotion of climate change information can also backfire. Based on these findings, we propose an agent-based model to address influences on anxiety and correlated pro-environmental actions in relation to societal attitudes of climate change scepticism and environmental self-identity.

Keywords: Climate Change, Social Contagion, Networks, Agent-Based, Threat and Defence, Pro-Environmental Behaviour, Denial.

Threat and Anxiety in the Climate Debate: *An Agent-Based Model to investigate Climate Scepticism and Pro-Environmental Behaviour*

Introduction

At a time when the worrying consequences of climate change can no longer be ignored, global warming has become a widely discussed issue. In response to the causal link between current climate change and man-made GHG emissions, environmental organisations, governments and involved stakeholders are trying to motivate citizens to adopt more environmentally friendly lifestyles by presenting information on the consequences of climate change. Although necessary steps to achieve a smaller footprint are well-known, the realisation of a greener lifestyle is proceeding slowly and has been facing stagnation for decades. There is currently no clear answer on how to accelerate the pace of this vital transition to avoid immediate threats to societies.

Despite the profound scientific findings on climate change, public and media discussion is often distorted and shifted to a discussion about whether the scientific facts are valid at all (Dunlap, 2013). While this shift in discussion bias is criticised by climate scientists among several voices, it is often unintentionally supported by failing to take sufficient account of the socio- psychological reasons that can lead to denial of climate change. Calling for social transformation towards a climate-friendly lifestyle through the dissemination of threatening information seems to be based on an intuitively correct assumption: more awareness of the problem of climate change also leads to more climate-friendly actions. The findings of threat and defence research indicate, however, that this approach can create unplanned effects and may also backfire (Uhl, Jonas, and Klackl, 2016).

Here we present an agent-based model of climate communication and the associated climate scepticism and pro-environmental behaviour, using the perspective of a socio-psychological model of threat and defence. Our main goal is to evaluate the model dynamics to identify conditions which can support favourable scenarios and to examine circumstances which enhance or dampen possible backfiring effects.

Threat and Defence Model: Theoretical Background

The social-psychological threat literature deals with reactions to problems such as personal uncertainty, loss of control, conflicting goals or perceptual surprises. Recently, an 'integrative general model of threat and defence processes' was developed by Jonas, McGregor, Klackl, Agroskin, Fritsche, Holbrook, Nash, Proulx, and Quirin (2014) that provides a conceptual framework for understanding such diverse phenomena. Based on societal psychological and neural perspectives on defensive reactions to threat, the model proposes the simple hypothesis that discrepancies arouse anxiety and thereby motivate diverse phenomena that activate approach-related states that can relieve anxiety.

From this perspective, threats result from an experience of the discrepancy between an expectation or a desire and the current circumstances. This discrepancy is followed by anxiety, which leads to a variety of proximal defence reactions such as avoiding the problem. The threat-related processing is mediated by the Behavioural Inhibition System (BIS), which responds with symptoms such as anxiety and avoidance. In case of potentially threatening information, individuals increase their efforts to suppress or distract and distance themselves from identified anxious thoughts or circumstances.

A second way of combat anxiety is to turn to approach-motivated behaviour. This reaction pattern manifests itself through the Behavioural Approach System (BAS). When activated, the possible responses include various strategies to seek an effective solution to the problem at hand. Activation is preferred when the discrepancy appears manageable. Since approach-motivated states are able to dampen anxiety and conflict, the anxious BIS stage is successively supplanted or shortened. In case of no available solutions to the threat (e.g., impending death due to ongoing sickness) individuals can nevertheless turn to approach-motivated states by indirectly solving the threat through soothing or mellowing reactive patterns.

In summary, the research of Jonas et al. (2014) suggests that people tend to evade threats over which they feel they have no control and try to relieve anxiety in a symbolic way by turning to more rewarding aspects of life, even if this aspects are unrelated to the actual threat at hand or its solution. However, in the course of time, most people eventually succeed in muting the BIS by engaging in distal approach-oriented reactions, regaining stability and overcoming this negative state. The BAS can be empowered by the pursuit of personal goals by providing a target for the approach-motivated behaviour. Personal goals can be derived from internal orientations (self-identity, values) or social norms.

Climate Change Information

How individuals process negative information about climate change is strongly influenced by their individual beliefs. By visiting several research efforts in the field of environmental psychology that investigated responses to environmental threats, we identify two significant characteristics that are reported as important drivers: (i) climate change scepticism (CCS) and (ii) biospheric values and environmental self-identity (ESI)[1]. Scepticism towards climate change correlates with the belief in a just, orderly and stable world. As a consequence, people with high CCS show only little intention of reducing their environmental footprint when confronted with threatening news (Feinberg and Willer, 2011). On the contrary, these information seem less convincing (Corner, Whitmarsh, and Xenias, 2012). People who are less sceptical are positively influenced in their environmental attitude when confronted with the same information. It has been shown that a high environmental self-identity (i.e. the extent to which you see yourself as a type of person who acts environmentally-friendly) increases pro-environmental behaviour (PEB) of people to whom negative environmental information is presented (Bolderdijk, Gorsira, Keizer, and Steg, 2013).

A recent study examined the responses to a threat exposure by climate information (Uhl et al., 2016; Uhl, Klackl, Hansen, and Jonas, 2018) with reference to

[1] Values are general and abstract principles that one strives for in life, while self-identity reflects how one sees oneself. We will limit further discussion to the latter terminology. See (Van der Werff, Steg, and Keizer, 2013) for a conceptual differentiation between environmental preferences, intentions and behaviour.

the threat and defence model (Jonas et al., 2014). Their findings indicate that strong environmental values can not only increase approach-motivated behaviour, but also promote symbolic reactions and can backfire by less willingness to take action, e.g. donate money to an environmental organization. Here, high ESI individuals resolve the threat partly by exhibiting higher PEB intentions, but the same individuals show symbolic defensive behaviour by looking more negatively at multiple groups, including criminals, overweight, or unattractive people. One possible explanation for this is that a higher ESI leads to a greater perceived threat to these participants, who are then unable to fully resolve the threat through purely direct behaviour.

Agent-Based Model

Several studies apply agent-based models (ABM) to the study of climate-related issues, with a strong focus on socio-economic and socio-ecological perspectives (Moss, Pahl-Wostl, and Downing, 2001; Soboll and Schmude, 2011; Valkering, Tabara, Wallman, and Offermans, 2009), agricultural modelling (Troost and Berger, 2014; Truelove, Carrico, and Thabrew, 2015) and adaptation processes in connection with climate policy (Balbi and Giupponi, 2010; Downing, Moss, and Pahl-Wostl, 2000; Gerst, Wang, Roventini, Fagiolo, Dosi, Howarth, and Borsuk, 2013) and migration (Hassani-Mahmooei and Parris, 2012; Kniveton, Smith, and Wood, 2011). Only a few socio-psychological models were developed, e.g. Smith, Anderson, and Moore (2012) analyses the perceived resilience of an individual to changing climatic conditions, (Truelove et al., 2015) implemented risk, coping, and social appraisal in agricultural adaptation processes in Sri Lanka. The process of individual adaptability on climate change via human cognition was investigated in (Grothmann and Patt, 2005). Important work on climate scepticism in a communication network perspective to predict climate change attitudes is presented in (Leombruni, 2015).

We like to contribute to the line of socio-psychological ABM research with a attitude-based model of climate communication. Individual agents have internal orientations that shape their response and the associated probability of environmental behaviour in confrontation with information about climate change. The agent architecture is based on the aforementioned threat and defence model (Jonas et al., 2014) and is backed by findings in (Uhl et al., 2016,1). In addition to response mechanisms to negative information, social contagion processes were implemented via interaction network topologies, for which we use scale-free and spatial-proximity networks to implement agent-to-agent communication. The model dynamics describe the temporal development of internal states of the agents and correlation of environmental actions.

Agent Architecture

We have implemented an internal, attitude-oriented state in connection with communication on climate change. We use the agent architecture (see Table 1) as a composition of an anxiety state (anx) induced by threatening information (e.g. about climate change) and internal orientations of climate change scepticism (ccs) and environmental self-identity (esi). When an agent receives information, an anxiety reaction Δanx is triggered Fig. 1 (left). The amount of anxiety increase depends on the value of an individual's ccs (colour code) and the information impact II (x-axis), i.e. how severe or negative the information is. Without detailed knowledge of the correlation of stimuli and reactions, we assume linearity. This linear response is added to the anxiety state anx of the individual, which increases most for low ccs and high information impact. If no information is received, the anxiety state follows a small natural rate of decay.

With regard to decision making, we implement a pro-environmental behaviour (peb) by using a probability to engage in environmental friendly actions. This probability can increase or decrease according to the values of esi and anx of an individual. The higher these parameters, the more likely an agent takes action. If an agent engages in a peb action, its anxiety is partly released which is linked to a decrease in peb probability. The correlation of the three parameters esi, anx, peb is given by a Hill function as shown in Fig. 1 (right) for different anxiety states.

To facilitate notation, we use lowercase letters when referring to parameter of single agents (esi, ccs, anx, peb) and capital letters when referring to collective means of the population (ESI, CCS, ANX, PEB). The mean of the initial distributions are denoted by $ESIinit, CCSinit$ (see Table 2). The collective orientations or bias of the population ESI, CCS are initially distributed randomly with $ESIinit \pm 0.2, CCSinit \pm 0.2$. We would like to point out that personal traits eventually have statistical correlations, so that there is a natural interdependence. In this generic approach we do not concern ourselves with the relationship between the two attributes of ESI and CCS and therefore treat the distributions as independent from each other.

External Information

In addition to documentaries, campaigns, journalistic articles and mouth-to-mouth communication as tools to mobilise public support and educate about climate change, online communication on climate change and climate politics has become increasingly popular and powerful. Although climate scientists and scientific institutions are eager to participate, they do not seem to be major players in online debates (Schäfer, 2012) and their impact on a broader public appears to be limited so far. The problem of effective communication to mobilise citizens to tackle climate change is inherent and reinforced by several factors (Cox, 2010). Since the focus of this study is on social-psychological response mechanisms to threat, a generic version of information streams is sufficient for the implementation of climate-related information.

We implement possible information streams as unified ‘external information’ given by the information density. Individuals are exposed to negative information, which can vary in severity and frequency. The severity can range from strong to light and is regulated by the information impact II. The information rate IR indicates the probability that an agent receives information in a time step. These two information parameters IR, II control the information density so that we can create scenarios ranging from ‘mild but frequent’ to ‘intensive but sparse’ exposure.

Social interactions

The shaping of public opinion through social interactions stems from a complex interplay between mental and social dynamics. This allows attitudes or opinions to emerge, spread and change on a population level. Agent-based modelling is particularly suitable for the study of dynamics involving heterogeneity and social contagion processes (Alvarez-Galvez, 2016; Nardin, Andrighetto, Conte, Székely, Anzola, Elsenbroich, Lotzmann, Neumann, Punzo, and Troitzsch, 2016; Schweitzer and Garcia, 2010; Sopha, Klöckner, and Hertwich, 2013; Tang, Wu, Yu, and Bao, 2015). We use networked ABM, in which interactions are based on an underlying network topology within a population N. We identify climate scepticism as the main contagious attitude with respect to social dynamics, and anxiety as a motivational impulse to participate in possible interactions about climate change. Thus, we model social contagion dynamics of climate change scepticism with a correlation to the internal anxiety level.: The higher the personal anxiety the more likely it is that an agent will communicate and influence one of its link-neighbours on climate scepticism. If an agent is more likely to believe in climate change $CCS < 0.5$, it can reduce the scepticism of one of its link-neighbours up to a maximal learning rate. On the other hand, if an agent denies climate change to a certain degree $CCS > 0.5$, that agent can increase the scepticism of a link-neighbour.

The model is limited to CCS contagion, while contagion processes of ESI and PEB are not considered. We believe that climate scepticism is the most contagious attitude for several reasons: First, in relation to the everlasting movement of climate change denial, the contagious effect of CCS has been shown to be highly influential among (some) members of society. Secondly, we believe that the denial of climate change is closely linked to the information received and less to a real and scientific understanding of the situation, which makes this dynamic even faster. Thirdly, environmental self-identity, which involves the process of forming one's own identity, has a stronger need for experience. Therefore, we believe that the time scale of CCS contagion processes is considerably faster and that social contagion processes of ESI are to some extent negligible for our modelling requirements.

The underlying network topology are scale-free networks that exhibit a distribution of degrees (i.e. number of links for each node) that follows a power law. We generated this type of topology using the preferential-attachment algorithm by (Barabási and Albert, 1999). In a second set of investigations to test the robustness of our results, spatial-proximity networks are used. These networks have a high clustering with the number of links in their spatial neighbourhood being given by the average degree d as introduced in (Stonedahl and Wilensky, 2008) to model spreading dynamics of epidemics (SIR model).

Simulations

We use the presented model in order to investigate different aspects of climate communication under ongoing external information flow and social contagion processes over successive rounds t. We do the following simulations using parameters presented in Table 2.

All simulations show temporal dynamics in CCS, ANX, and PEB while ESI and the information density parameters II, IR are fixed for each run.

Simulations for the purpose of calculating final states have a time range of $T = 2000 - 10000$ plus 500 time steps. The last 500 steps are used for calculating the equilibrium as mean value. The respective simulated total time T depends on the occurrence of an equilibrium. The equilibrium state is reached when the CCS contagion process is complete and the variations of the collective CCS are less than 10^{-3}. For almost all simulations, we found equilibration before $T = 10000$. In the extremely rare case that a simulation did not equilibrate before $T = 10000$, we examined the results individually and found that very small fluctuations are slightly above our chosen equilibration criterion but no trend in the CCS development was visible for the last 5000 time steps. Simulations for the representation of the temporal development are shortened and serve only the illustration of the dynamics.

Results

Our aim is to compare favourable scenarios of high environmentally friendly behaviour with unfavourable scenarios of low environmentally friendly behaviour. We want to emphasize the conditions that are necessary for pro-environmental behaviour. For this, we present different analyses of our model, which can be divided into studies on

1. the temporal development of the collective state,
2. the equilibrium results of the collective state, and
3. the heterogeneity of behaviour in the population.

In order to illustrate the influence of the flow of information, we compare scenarios with low, medium and high information density. We use a rigorous parameter analysis of the orientations ESI and CCS, which represent the bias of the population on climate change. This allows us to compare the behaviour of populations of weak to strong environmental self-identity and low to high climate change scepticism. We compare these results on two different interaction topologies (scale-free networks and spatial-proximity networks). To give more insight into trends within a population, we compare the behaviour of climate change 'believers' and climate change 'deniers' as a sub-investigation of the parameter analysis of the internal orientations. We discuss the main effects of the information density on the dynamics and some minor effects regarding the temporal development and similarities under 'mild but frequent' to 'intensive but sparse' exposure.

To simplify the understanding of the results we distinguish the parameter space of ESI, CCS in four quadrants A, B, C and D. Each quadrant represents populations with a specific bias. Quadrant A: more sceptical and less environment-oriented, quadrant B: more sceptical and more environment-oriented, quadrant C: less sceptical and less environment-oriented, and quadrant D: less sceptical and more environment-oriented. The balanced population of $ESI = 0.5$ and $CCS = 0.5$ is centred in-between the quadrants.

Temporal Evolution

Each simulations starts with no anxiety $ANX = 0$ and, therefore, no probability to perform PEB. The continuing exposure to information of rate IR and impact II increases the anxiety level which is then followed by a PEB response. This response is delayed due to the necessity of a certain anxiety level to emerge within the population. The initial mean distribution in the scepticism CCS transforms over time due to interactions of individuals, which is delayed for the same reason than the PEB response. Fig. 2 shows this processes for a balanced population under exposure of medium information density: First, an increase in anxiety is visible while the PEB probability and CCS distribution are steady. With a delay, the CCS normal distribution is dispersed and strong believers ($CCS < 0.1$) and strong deniers ($CCS > 0.9$) become more frequent while the rest of the opinion range is uniformly present. At $t = 2000$, an equilibrium state is reached with rather high anxiety but lower PEB probability and the population is divided in two unequal groups of strong believers and strong deniers.

The evolution of the collective anxiety level and the correlating PEB actions are shown in Fig. 3 for low, medium and high information density. The results for 20 simulations are given by mean (line) and standard deviations (shaded areas, only visible for PEB at high density). The balanced population with $mESI = mCCS = 0.5$ is investigated. Comparing these results, the anxiety level in the medium and high density scenario are similar while the correlated approach-motivated behaviour at high density is more than doubled for the medium density case. At low density, an increase in anxiety level is observed but no approach-motivated behaviour occurs.

Similar results can be obtained by using smaller populations $N = 1000$ (see appendix Fig. 7). No major scaling effects by variations in population size have been observed.

Dependence on Environmental Self-Identity and Climate Change Scepticism

The initial configuration of the population, i.e. whether it is a population with low or high environmental values or climate scepticism (four quadrants), is decisive for the outcome of the behaviour patterns. To test the dependence of the PEB probability on the internal parameters ESI and CCS of the agents, we perform a complete parameter variation, as shown in Fig. 4. Here the initial distributions of both parameters are varied with $ESI \in [0.01, 1]$ and $CCSinit \in [0.01, 1]$. The results are given for the collective anxiety ANX (left column, Fig. 4) and the collective PEB probability (right column, Fig. 4). The initial mean parameters $mESI, mCCS$ are reflected by the x, y-axis. Results are displayed for the mean of 10 (high) and 5 (low) simulation runs for each set of parameters.

In the case of low information density (top), the collective anxiety is increased in quadrant C, while the other quadrants exhibit rather low anxiety levels. Moreover, for all quadrants the correlated PEB probability is not significant (≈ 0.006) with only a minor increase of 0.012 in quadrant D for populations of very high environmental self-identity $ESI > 0.9$ (not visible in the colour code).

In the case of high information density (bottom), a correlation of the collective anxiety to the collective CCS value is visible. Populations of high climate scepticism in quadrant A, B ($CCS > 0.5$) exhibit low anxiety. Populations of higher believe in climate change of quadrant C, D ($CCS < 0.5$) show higher anxiety levels, with a stronger increase in quadrant C. However, we only observe a positive correlation of the anxiety level and favourable PEB increase for populations with high $ESI > 0.5$ in quadrant D. Populations of other quadrants show no significant increase in the PEB probability and thus are considered unfavourable. We conclude that for sufficient environmental bias the collective behavioural response with PEB is possible.

The results from Fig. 4 are generated using scale-free networks, which represent a common network topology for societal processes. To test the robustness of our results towards other network types, we explore the same model dynamics on spatial-proximity networks. By using a second topology, we were able to achieve very similar results. Quadrant A and C do not show PEB responses and quadrant D reacts approach-motivated with increased PEB. In quadrant B an improvement of PEB responses takes place, dividing the quadrant into two areas with and without PEB

response, as can be seen in the appendix Fig. 8.

Climate Scepticism Dynamics

Another important aspect of changes in climate scepticism with regard to the amount of information a population is exposed to. To illustrate the social contagion processes on CCS, we examine the relative changes between initial climate scepticism ($CCSinit$) in a population and the collective equilibrium state CCS, shown in Fig. 5 (left). Values of CCS below the dashed line indicate a decrease in in respect to the initial configuration, while values above CCS indicate an increase in collective CCS.

We show the results for three cases of information density: low ($II = 0.1, IR = 0.1$), medium ($II = 0.5, IR = 0.5$), and high ($II = 0.9, IR = 0.9$). Interestingly, the higher the information density, the stronger the CCS increase for same initial configurations. Taking the balanced population at $CCSinit = 0.5$ as an example, we observe a decrease of CCS for all information densities. Inspection of the correlated timelines (not shown) revealed that for the high density case this final decrease in CCS was preceded by a small intermediate increase of $CCS \approx 0.6$ which ultimately declined towards $CCS \approx 0.3$.

To highlight the correlating PEB actions for these three scenarios, Fig. 5 (right) shows the effect of the information density on the collective PEB. Here, the highest probabilities are given in the case of high information density. We conclude that if the mean initial scepticism is not above 60% the overall positive effect of high information density by enabling agents to increase PEB exceeds the negative effect of higher collective CCS.

Believers and Deniers

The evolution of the collective CCS transforms the initial normal distribution around the initial mean value $CCSinit$ into distinct groups of low and high climate scepticism, as presented in Fig. 2. Since the agent architecture does not include intelligent actions, i.e. agents cannot change their opinions by logical thinking when presented with convincing evidence, this sharp division is a result of the social contagion and a typical phenomenon for generic agent-based modelling without noise. In order to further investigate this division and its consequences, we categorize the population into two groups. The 'believers' are those whose CCS is below 50%, the 'deniers' are the agents whose CCS is above 50%. We study the parameter dependencies and different behaviour patterns of both groups over the parameter space of internal orientations ESI, CCS (see for comparison Fig. 4).

One of the most important properties is the group size, N_B of the believers and N_D of the deniers. There is a naturally correlating relationship of the resulting group sizes that is proportional to the initial mean of the normal distribution of scepticism $CCSinit$. The higher $CCSinit$ the higher the number of N_D and vice versa (see Fig. 6 (top left)). Now it is of interest whether this development is affected by the environmental self-identity, especially in the case of high information density, which enables agents to resolve anxiety by responding with PEB actions in quadrant D. Fig. 6 (top) depicts these results in respect both collective orientations ESI and $CCSinit$. Here the mean value (line) and standard deviation (shaded area) are given over different values of ESI and are displayed on the x-axis for each value of $CCSinit$. Therefore, curves with a small standard deviation show that the dependence on ESI is negligible. We conclude that the resulting population share sizes N_B, N_D (top left) have a correlation with $CCSinit$ only, while the final values of CCS (top right) are constant and have no correlation to both initial internal orientations.

Fig. 6 (bottom) shows a similar investigation for believers and deniers and their levels of anxiety and pro-environmental behaviour in relation to both internal orientations. Here the perspective on CC and ESI is inverted: Values with identical $CCSinit$ are averaged and the correlation to ESI is depicted by the x-axis. The mean value (line) and the standard deviation (shaded area) of ANX and PEB are given. This inversion is feasible due to the natural dependence of PEB on the environmental self-identity and verified by the small standard deviations of three out of four curves. Only the anxiety of the deniers displays both dependencies of ESI and $CCSinit$. It should also be noted that believers are exclusively contributing to PEB while deniers do not respond with any increase in PEB. Therefore, favourable results of quadrant D (see Fig. 4 (bottom right)) is solely due to the believers, which are motivated to respond with PEB. The deniers can be regarded as free-riders (Heitzig, Lessmann, and Zou, 2011), who benefit from the actions of others without contributing, as they are not willing to contribute. Thus, the group sizes N_B, N_D are a major influence on the success of the whole population.

In the appendix, this investigation is shown for low information density (Fig. 9). Additionally, we provide the results on the complete parameter-plane of ESI and $CCSinit$ for both groups of believers and deniers on which this evaluation is based on (low density: Fig. 10, and high density: Fig. 11).

Effects of Information Density

The primary effects of information density encompass a strong influence on the collective anxiety levels and pro-environmental behaviour. However, the positive correlation of favourable PEB progression with increasing information density is only given if certain additional conditions regarding the internal orientations (ESI, CCS) are met (see Fig. 3, 4). Another major aspect is the positive correlation of climate scepticism with increasing information density (see Fig. 5)

We would like to add two minor aspects of the impact of information density to the discussion to complete this picture. First, the dynamics of CCS development is slower at low information density than at high. This is caused by a weaker increase in the anxiety levels of individuals and thus a lower probability of participating in communication between agents. Second, with regard to the two density parameters, we have tested whether the information effect or the information rate has a different effect on the results and the balancing time. We tested high rates with low load and the reverse case of high load and low rate. Here we found only a slight difference in the results and runtimes in favor of the information rate. Since the difference is 1%, we do not draw any further conclusions.

Limitations and Outlook

To implement the socio-psychological theory of threat and defence of Jonas et al. (2014) in a networked ABM, we have chose several simplifications to obtain a generic model that can be further extended in future research efforts. Possible extensions or improvements are given in regard to 1) agent architecture and social contagion processes, 2) data on internal orientations (environmental self-identity, climate scepticism), 3) information flow and information processing, and 4) including anxiety release via symbolic defensive behaviour, to name but a few. In order to deal with the questions arising from this work in further detail, we will work on the aspects mentioned below as described below:

1) Further development of the agent architecture is provided, e.g. by the Belief-Obligation-Desire-Intention BOID architecture (Broersen, Dastani, Huang, Hulstijn, and Torre, 2001) where social agents are capable to resolve different conflict types within or among informational and motivational attitudes.

2) Advancing from generic parameter exploration towards more detailed studies, the attribute composition of the population and internal architecture can be improved (distribution, quantity and interrelation) by drawing upon datasets, i.e. from the International Social Survey Programme, Environment Module III (ISSP) provided by the Zentralarchiv für Empirische Sozialforschung, University of Cologne in the GESIS Data Archive (`http://zacat.gesis.org/`).

2) In addition to social contagion influences on climate scepticism the external information and correlated information processing can impact opinion dynamics within a population. Implementation of a direct influence of scepticism through convincing or persuasive information represents a meaningful extension of the model.

4) The model represents a closed system, where agent's only option to reduce anxiety is by approach-motivated behaviour or small natural decrease when not

confronted with negative information. We are looking forward to conceptualize a model version that takes into account the anxiety reduction of the resulting symbolic defensive behaviour that manifests itself, for example, as ethnocentrism or other discriminatory behaviour.

Ultimately, efforts to model communication on climate change should not only help us to understand how related social norms are formed and passed on, but also enrich our knowledge about how to manage the transformation towards a greener lifestyle. With this in mind, we intent to further improve the model capacities in the near future and to provide a supporting tool for critical reflection on the key challenges in connection with climate change mitigation. We would like to emphasize that our understanding of ABM does not include predictive power, but the nature of the model as presented in this work serves the purpose of enrichment of the discourse.

Conclusion

In this study, we investigated the climate debate from the socio-psychological perspective of thread and defence research by developing and analysing an agent-based model. We focus on long-term population-based effects that can be caused by information about climate change. In a nutshell, the dynamics follow a few simple principles: The exposure of threatening information may cause an anxiety response of an individual which then can be released by approach-motivated pro-environmental behaviour. The actual increase in environmentally friendly behaviour is subject to several factors, such as internal orientations on climate change and environmental self-identity, but also on the amount of received information.

In general, the confrontation with the consequences of climate change does not increase the pro-environmental intent unless several conditions are met:

1. The amount of information has to be large enough to encourage approach-motivated action, otherwise the anxiety increases but does not sufficiently promote such behaviour.

2. The majority of the population has a well-developed environmental self-identity, otherwise they lack in motivation to respond with environmental friendly behaviour.

3. The majority of the population should strongly believe in climate change, otherwise free-riding of climate change deniers reduce the overall success of the population.

An important side effect that we observed was in correlation to the amount of information density. We observed a relative increase in public scepticism the more information was provided. This reflects an alternative way of dealing with anxiety by avoiding restless thoughts and moving away from them. Encouragingly, environmentally friendly actions were positively correlated to information increase and this effect more than compensated for the negative effects of increasing scepticism.

We would like to highlight some of our most important insights of the model dynamics:

- An increased anxiety about climate change is not necessarily associated with greener lifestyle.

- High information density about climate change is not necessarily correlated with favourable scenarios, while low information density will always lead to unfavourable scenarios.

- The number of climate change believers is important for the success of a population, while climate change deniers are free-riding.

- Believers in climate change of low environmental orientations are highly anxious but refrain from approach-motivated behaviour, which is particularly important in regard to symbolic defensive behaviour (backfiring effect).

- Believers in climate change of high environmental orientation engage in sufficient environment friendly lifestyles only if high amounts of information are continuously provided.

- Initial high values on climate scepticism hinder the population to develop anxiety while the minority of believers are highly anxious but muted by the denying majority.
- Balanced societies without a bias in scepticism evolved towards less scepticism, while this trend was dampened the more information was distributed.
- Initially highly sceptical societies showed trends towards even more scepticism, while this trend was intensified as more information was distributed.

Regarding the non-zero anxiety states for all levels of environmental friendly orientations, our research is in line with the results in Uhl et al. (2016), which showed that both groups of low and high environmental self-identity can show symbolic responding in order to release anxiety.

Drawing a general conclusion on the observed collective behaviour of the modelled population, we find that the conditions under which a transition to greener lifestyles takes place are very narrow. In order to motivate the population, an explicitly high ecological identity alone is not sufficient, but it would also require an ongoing high information load, which, realistically, cannot be achieved in real-world systems. We believe that this indicates that a self-regulated transition, meaning that individuals choosing voluntarily to change behaviour permanently, is rather unlikely. This leads us to conclude that systemic regulation, including environmental laws, sanctions for exceeding footprints, and financial incentives is needed to enable a transition towards sustainable societies. This portrayal is model-based only and might be rather pessimistic, since we did not include several powerful motivators, such as hope in the context of climate change (Chadwick, 2015) or overcoming scepticism, for example through education (Stevenson, Peterson, Bondell, Moore, and Carrier, 2014).

References

Javier Alvarez-Galvez. Network models of minority opinion spreading: Using agent-based modeling to study possible scenarios of social contagion. *Social Science Computer Review*, 34(5):567–581, 2016.

Stefano Balbi and Carlo Giupponi. Agent-based modelling of socio-ecosystems: a methodology for the analysis of adaptation to climate change. *International Journal of Agent Technologies and Systems*, 2(4):17–38, 2010.

Albert-László Barabási and Réka Albert. Emergence of scaling in random networks. *science*, 286(5439):509–512, 1999.

Jan Willem Bolderdijk, Madelijne Gorsira, Kees Keizer, and Linda Steg. Values determine the (in) effectiveness of informational interventions in promoting pro-environmental behavior. *PloS one*, 8(12):e83911, 2013.

Jan M Broersen, MM Dastani, Zhisheng Huang, Joris Hulstijn, and Lvd Torre. The boid architecture; conflicts between beliefs, obligations, intentions and desires. *Proceedings of the fifth international conference on Autonomous agents*, 2001.

Amy E Chadwick. Toward a theory of persuasive hope: Effects of cognitive appraisals, hope appeals, and hope in the context of climate change. *Health communication*, 30(6):598–611, 2015.

Adam Corner, Lorraine Whitmarsh, and Dimitrios Xenias. Uncertainty, scepticism and attitudes towards climate change: biased assimilation and attitude polarisation. *Climatic change*, 114(3-4):463–478, 2012.

J Robert Cox. Beyond frames: Recovering the strategic in climate communication. *Environmental Communication*, 4(1):122–133, 2010.

Thomas E Downing, Scott Moss, and Claudia Pahl-Wostl. Understanding climate policy using participatory agent-based social simulation. In *International Workshop on Multi-Agent Systems and Agent-Based Simulation*, pages 198–213. Springer, 2000.

Riley E Dunlap. Climate change skepticism and denial: An introduction. *American behavioral scientist*, 57(6):691–698, 2013.

Matthew Feinberg and Robb Willer. Apocalypse soon? dire messages reduce belief in global warming by contradicting just-world beliefs. *Psychological science*, 22(1): 34–38, 2011.

Michael D Gerst, Peng Wang, Andrea Roventini, Giorgio Fagiolo, Giovanni Dosi, Richard B Howarth, and Mark E Borsuk. Agent-based modeling of climate policy: An introduction to the engage multi-level model framework. *Environmental modelling & software*, 44:62–75, 2013.

Torsten Grothmann and Anthony Patt. Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Global Environmental Change*, 15(3):199–213, 2005.

Behrooz Hassani-Mahmooei and Brett W Parris. Climate change and internal migration patterns in bangladesh: an agent-based model. *Environment and Development Economics*, 17(6):763–780, 2012.

Jobst Heitzig, Kai Lessmann, and Yong Zou. Self-enforcing strategies to deter free-riding in the climate change mitigation game and other repeated public good games. *Proceedings of the National Academy of Sciences*, 108(38):15739–15744, 2011.

Eva Jonas, Ian McGregor, Johannes Klackl, Dmitrij Agroskin, Immo Fritsche, Colin Holbrook, Kyle Nash, Travis Proulx, and Markus Quirin. Threat and defense: From anxiety to approach. In *Advances in experimental social psychology*, volume 49, pages 219–286. Elsevier, 2014.

Dominic Kniveton, Christopher Smith, and Sharon Wood. Agent-based model simulations of future changes in migration flows for burkina faso. *Global Environmental Change*, 21:S34–S40, 2011.

Lisa V Leombruni. How you talk about climate change matters: A communication network perspective on epistemic skepticism and belief strength. *Global Environmental Change*, 35:148–161, 2015.

Scott Moss, Claudia Pahl-Wostl, and Thomas Downing. Agent-based integrated assessment modelling: the example of climate change. *Integrated Assessment*, 2 (1):17–30, 2001.

Luis G Nardin, Giulia Andrighetto, Rosaria Conte, Áron Székely, David Anzola, Corinna Elsenbroich, Ulf Lotzmann, Martin Neumann, Valentina Punzo, and Klaus G Troitzsch. Simulating protection rackets: a case study of the sicilian mafia. *Autonomous Agents and Multi-Agent Systems*, 30(6):1117–1147, 2016.

Mike S Schäfer. Online communication on climate change and climate politics: a literature review. *Wiley Interdisciplinary Reviews: Climate Change*, 3(6):527–543, 2012.

Frank Schweitzer and David Garcia. An agent-based model of collective emotions in online communities. *The European Physical Journal B*, 77(4):533–545, 2010.

Jordan W Smith, Dorothy H Anderson, and Roger L Moore. Social capital, place meanings, and perceived resilience to climate change. *Rural Sociology*, 77(3): 380–407, 2012.

Anja Soboll and Juergen Schmude. Simulating tourism water consumption under climate change conditions using agent-based modeling: the example of ski areas. *Annals of the Association of American Geographers*, 101(5):1049–1066, 2011.

Bertha Maya Sopha, Christian A Klöckner, and Edgar G Hertwich. Adoption and diffusion of heating systems in norway: coupling agent-based modeling with empirical research. *Environmental Innovation and Societal Transitions*, 8:42–61, 2013.

Kathryn T Stevenson, M Nils Peterson, Howard D Bondell, Susan E Moore, and Sarah J Carrier. Overcoming skepticism with education: interacting influences of worldview and climate change knowledge on perceived climate change risk among adolescents. *Climatic change*, 126(3-4):293–304, 2014.

Forrest Stonedahl and Uri Wilensky. Netlogo virus on a network model., 2008. URL `http://ccl.northwestern.edu/netlogo/models/VirusonaNetwork`. Accessed: 2019-01-04.

Ling Tang, Jiaqian Wu, Lean Yu, and Qin Bao. Carbon emissions trading scheme exploration in china: A multi-agent-based model. *Energy Policy*, 81:152–169, 2015.

Christian Troost and Thomas Berger. Dealing with uncertainty in agent-based simulation: farm-level modeling of adaptation to climate change in southwest germany. *American Journal of Agricultural Economics*, 97(3):833–854, 2014.

Heather Barnes Truelove, Amanda R Carrico, and Lanka Thabrew. A socio-psychological model for analyzing climate change adaptation: A case study of sri lankan paddy farmers. *Global Environmental Change*, 31:85–97, 2015.

Isabella Uhl, Eva Jonas, and Johannes Klackl. When climate change information causes undesirable side effects: the influence of environmental self-identity and biospheric values on threat responses/cuando la información sobre el cambio climático tiene efectos indeseados: la influencia de la identidad ambiental y de los valores biosféricos en la respuesta ante una amenaza. *Psyecology*, 7(3):307–334, 2016.

Isabella Uhl, Johannes Klackl, Nina Hansen, and Eva Jonas. Undesirable effects of threatening climate change information: A cross-cultural study. *Group Processes & Intergroup Relations*, 21(3):513–529, 2018.

Pieter Valkering, David Tabara, Patrik Wallman, and Astrid Offermans. Modelling cultural and behavioural change in water management: an integrated, agent based, gaming approach. *Integrated Assessment*, 9(1), 2009.

Ellen Van der Werff, Linda Steg, and Kees Keizer. The value of environmental self-identity: The relationship between biospheric values, environmental self-identity and environmental preferences, intentions and behaviour. *Journal of Environmental Psychology*, 34:55–63, 2013.

Table 1

Agent internal state and attitudes: parameters, ranges and explanations.

	Name	Value	Explanation
esi	Environm. Self-Identity	$\in [0,1]$	Agent's individual environmental orientation
ccs	Climate Change Scepticism	$\in [0,1]$	Agent's individual belief in climate change
anx	Anxiety	$\in [0,1]$	Agent's internal anxiety state towards negative information on climate change
peb	Pro-Environm. Behaviour	$\in [0,1]$	Agent's approach-motivated probability

Table 2

Model parameters, ranges and explanations of the full set of simulation parameters.

	Name	Value	Explanation
ESI	Environmental Self-Identity	$\in [0, 1]$	Mean population environmental orientation
CCS	Climate Change Scepticism	$\in [0, 1]$	Mean population belief in or denial of climate change
ANX	Anxiety	$\in [0, 1]$	Mean population anxiety towards negative information on climate change
PEB	Pro-Environmental Behaviour	$\in [0, 1]$	Mean population approach-motivated behaviour probability
N	Population	$1000, 10000$	Number of agents on the network
T	Time	$2000 - 10000$	Simulation time steps until equilibrium CCS is reached
IR	Information Rate	$\in [0, 1]$	Probability of an agent to receive external information in each time step
II	Information Impact	$\in [0, 1]$	Severity of external information received by agents
$ESIinit$	Initial mean ESI	$\in [0, 1]$	Population ESI distribution given by $ESIinit \pm 0.2$, remains constant ($ESIinit = ESI$)
$CCSinit$	Initial mean CCS	$\in [0, 1]$	Initial collective CCS distribution of the population is given by $CCSinit \pm 0.2$
Δanx	Anxiety increase	$\in [0, 0.1]$	Agent's anxiety response towards external information
–	Natural anxiety decrease	0.01	Agent's continuous anxiety decay without exposure to external information
–	*peb* anxiety release	0.25	Agent's anxiety drop induced by PEB action
–	*ccs* learn rate	0.05	Agent's maximal learn rate for social contagion related to climate scepticism

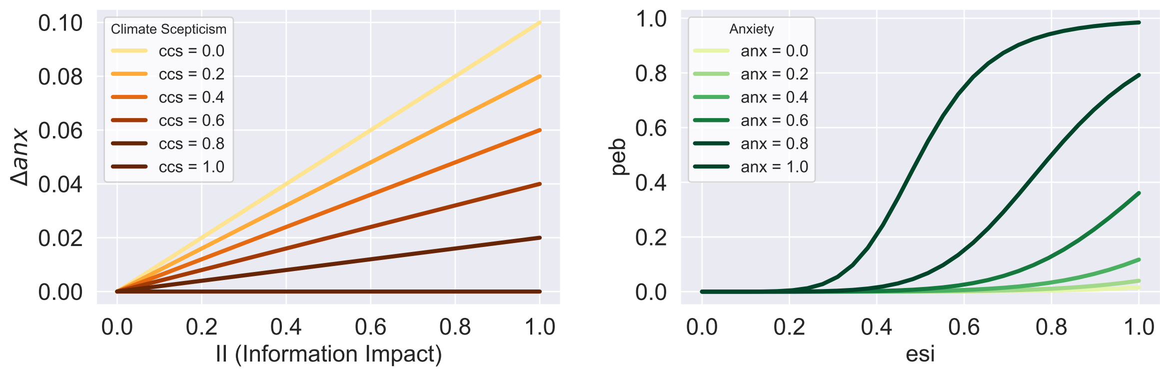

Figure 1. Agent architecture: (left) Anxiety response Δanx in relation to the information impact shown for six different *ccs* values; (right) agents *peb* probability in dependence of the environmental self-identity *esi* shown for different six different anxiety states *anx*.

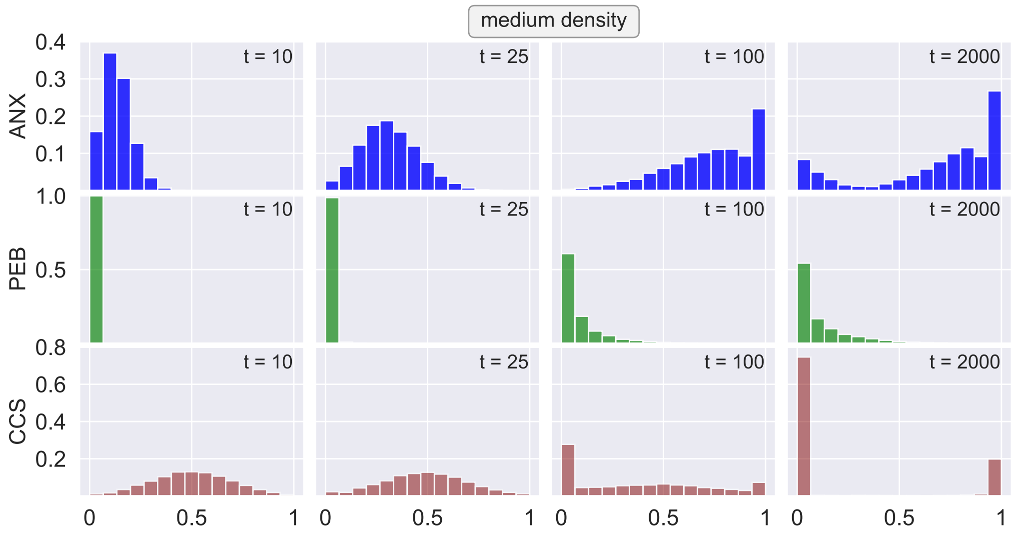

Figure 2. Temporal evolution of heterogeneous behaviour: evolution stages of PEB (green), ANX (blue) and CCS (brown) shown in four chronological time steps $t = 10, 25, 100, 2000$ (from left to right). The balanced population of initial distributions around $ESI = 0.5, CCSinit = 0.5$ is exposed to a medium information density, representing the moderate case of development patterns. Parameter $II = 0.5, IR = 0.5, N = 10000$.

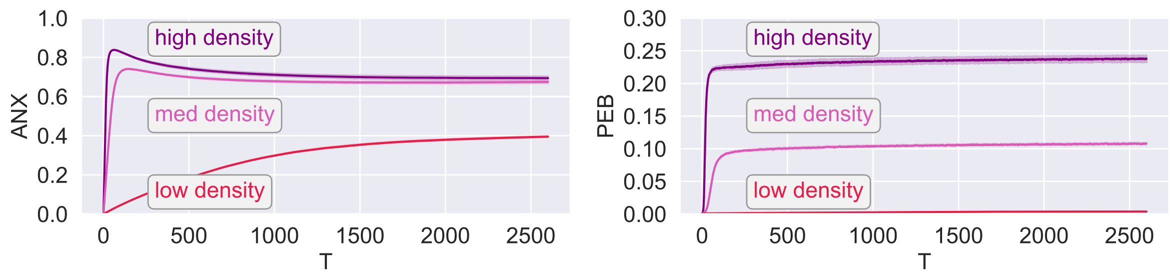

Figure 3. Time evolution of collective anxiety ANX (left) and collective pro-environmental behaviour PEB (right) for three different information densities: low ($II = 0.1, IR = 0.1$), medium ($II = 0.5, IR = 0.5$), and high ($II = 0.9, IR = 0.9$). Results show mean values (lines) and standard deviations (shaded area) of 20 simulation runs. Parameter: $N = 10000, ESI = 0.5, CCSinit = 0.5$.

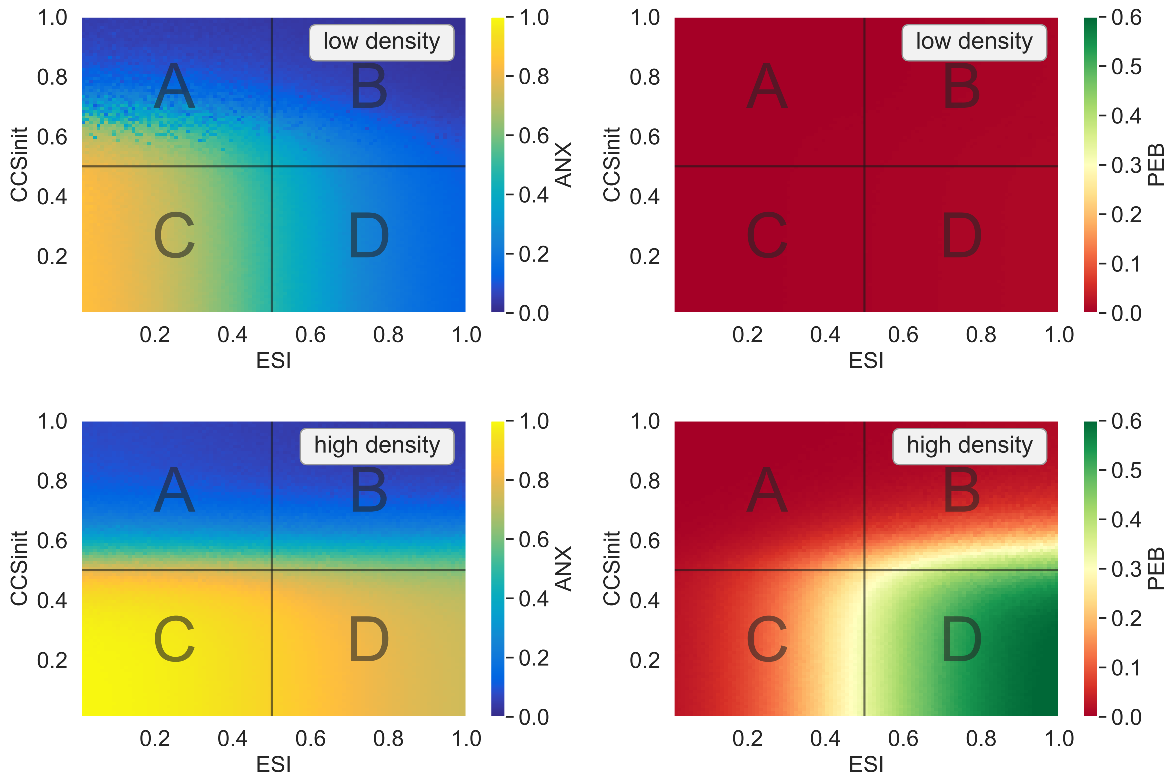

Figure 4. Dependence on population bias: Exploration of the initial orientations ESI and $CCSinit$ on the population behaviour for (top) low ($II = 0.1, IR = 0.1$), and (bottom) high ($II = 0.9, IR = 0.9$) information density. Results shown for (left) collective anxiety ANX, and (right) pro-environmental behaviour PEB, average taken over 5 (low) and 10 (high) simulation runs. Colour code as shown in the colour bar. Parameter $N = 1000$, scale-free topology.

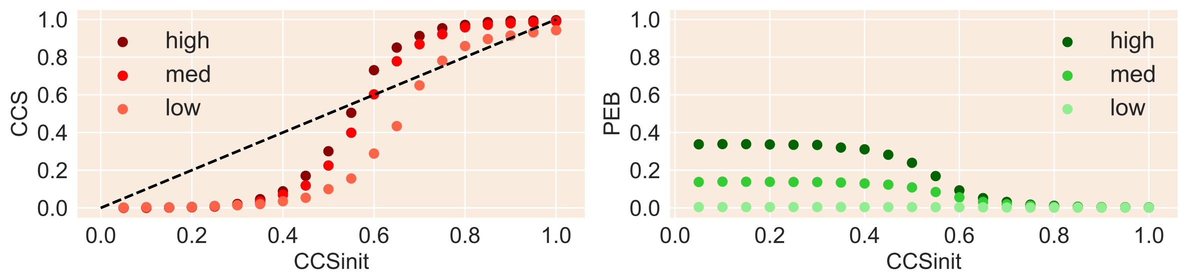

Figure 5. Dependence on initial climate change scepticism: correlation of initial $CCSinit$ and resulting (left) climate change scepticism CCS and (right) pro-environmental behaviour PEB. Results shown for three different information densities (low, medium, high) as shown in the legend. Parameter: $N = 1000, ESI = 0.5$.

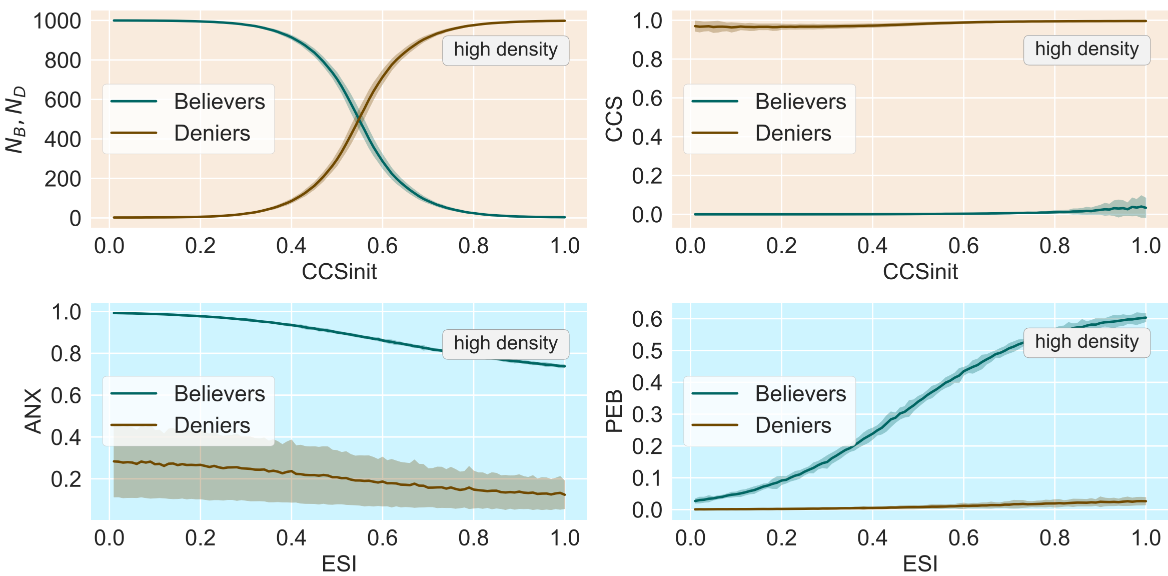

Figure 6. Believers and deniers: dependency of both groups on the internal orientations ESI, CCS in the high information density scenario. (top left) population share sizes N_B, N_D (top right) CCS equilibrium values, (bottom left) anxiety ANX, and (bottom right) pro-environmental behaviour PEB. Parameter: $N = 1000, II = 0.9, IR = 0.9$

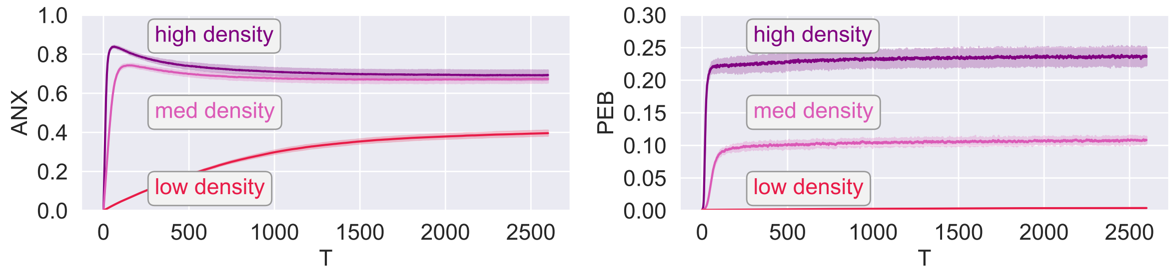

Figure 7. Time evolution of population of size $N = 1000$: (left) collective anxiety ANX, (right) and pro-environmental behaviour PEB for three different information densities with low ($II = 0.1, IR = 0.1$), medium ($II = 0.5, IR = 0.5$), and high ($II = 0.9, IR = 0.9$) given by the colour code. Results show mean values (lines) and standard deviations (shaded area) of 20 simulation runs. Parameter: $N = 1000, ESI = 0.5, CCSinit = 0.5$.

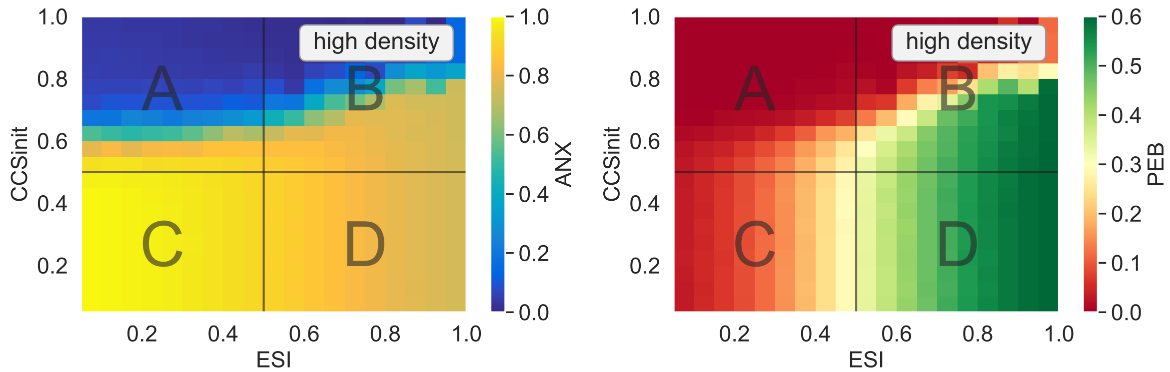

Figure 8. Dependence on population bias with spatial-proximity networks: Exploration of the initial orientations ESI and $CCSinit$ on the population behaviour for high information density. Results for (left) collective anxiety ANX, and (right) pro-environmental behaviour PEB , average taken over 20 simulation runs. Colour code given in the colour bar. Parameter
$N = 1000, II = 0.1, IR = 0.1, T = 2000 - 10000$, average degree $d = 6$.

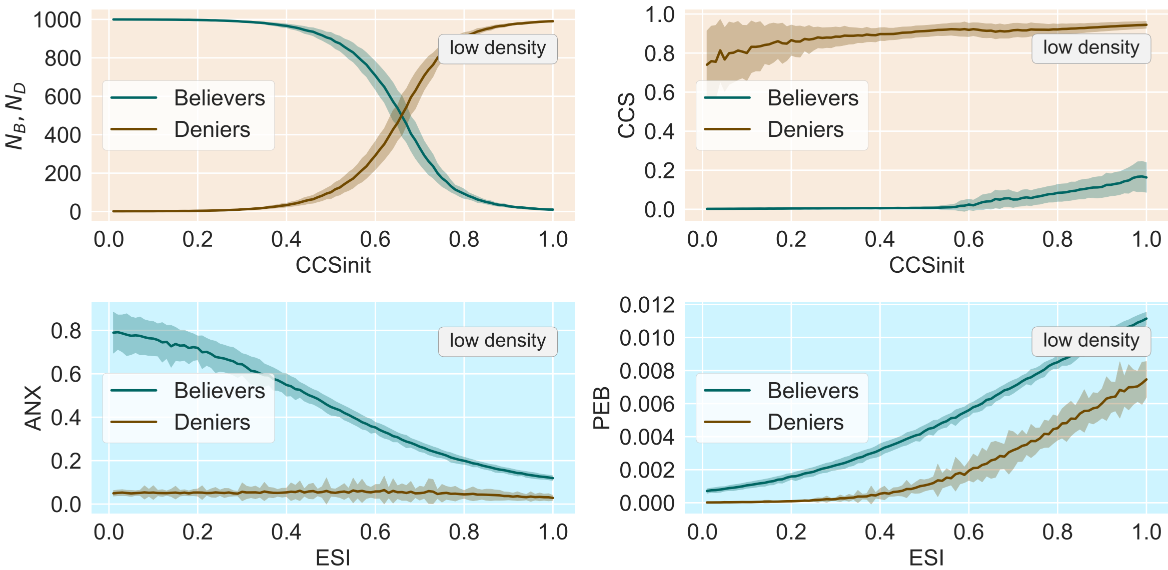

Figure 9. Believers and deniers: dependency of both groups on the internal orientations ESI, CCS in the low information density scenario. (top left) population share sizes N_B, N_D (top right) CCS equilibrium values, (bottom left) anxiety ANX, and (bottom right) pro-environmental behaviour PEB. Parameter: $N = 1000, II = 0.9, IR = 0.9$

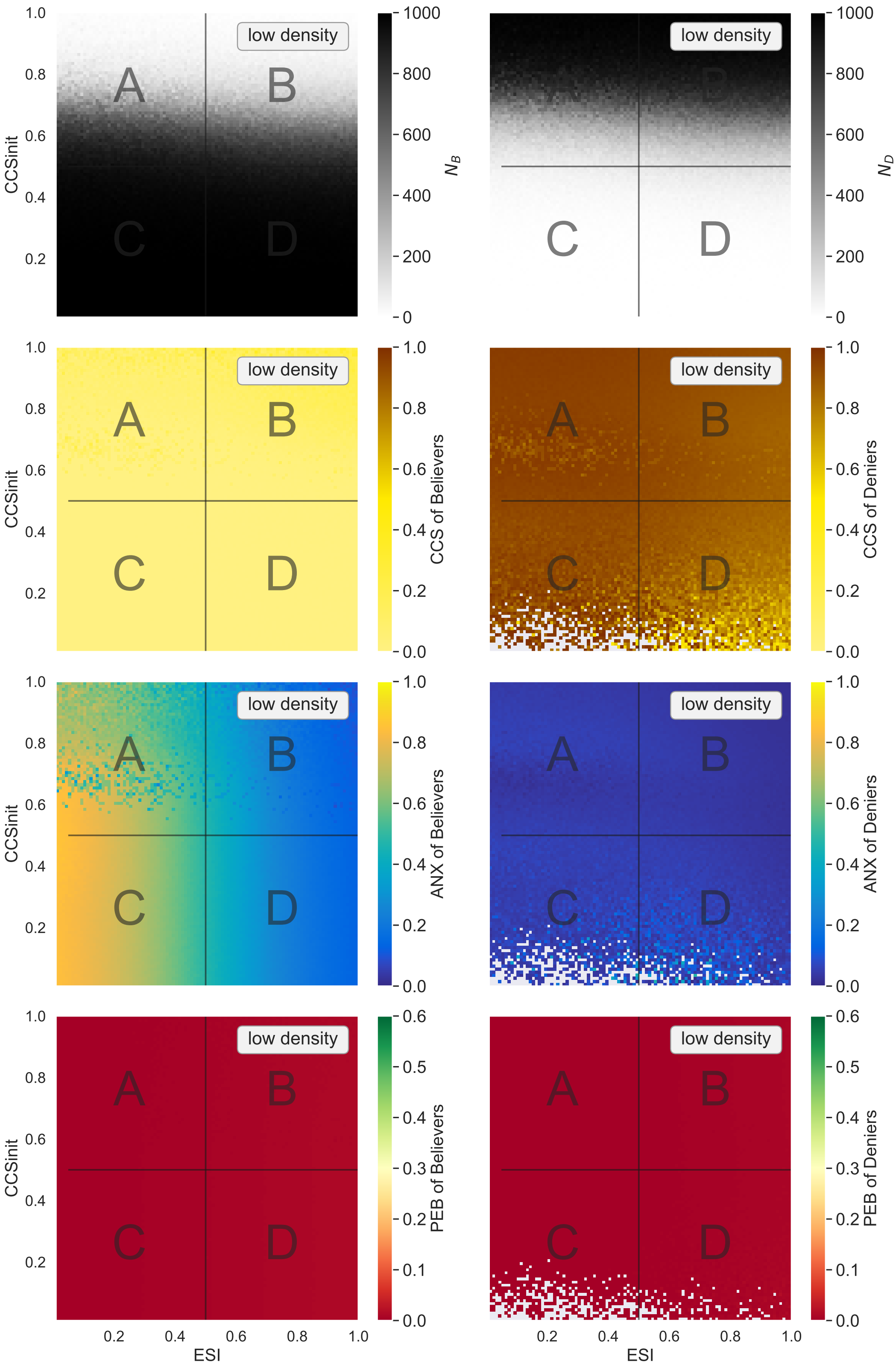

Figure 10. Believers and deniers full parameter plane: Exploration of the initial orientations ESI and $CCSinit$ for the low density case $II = 0.1, IR = 0.1$, (left column) believers and (right column) deniers. Parameter

$N = 1000, II = 0.1, IR = 0.1, T = 2000 - 10000$.

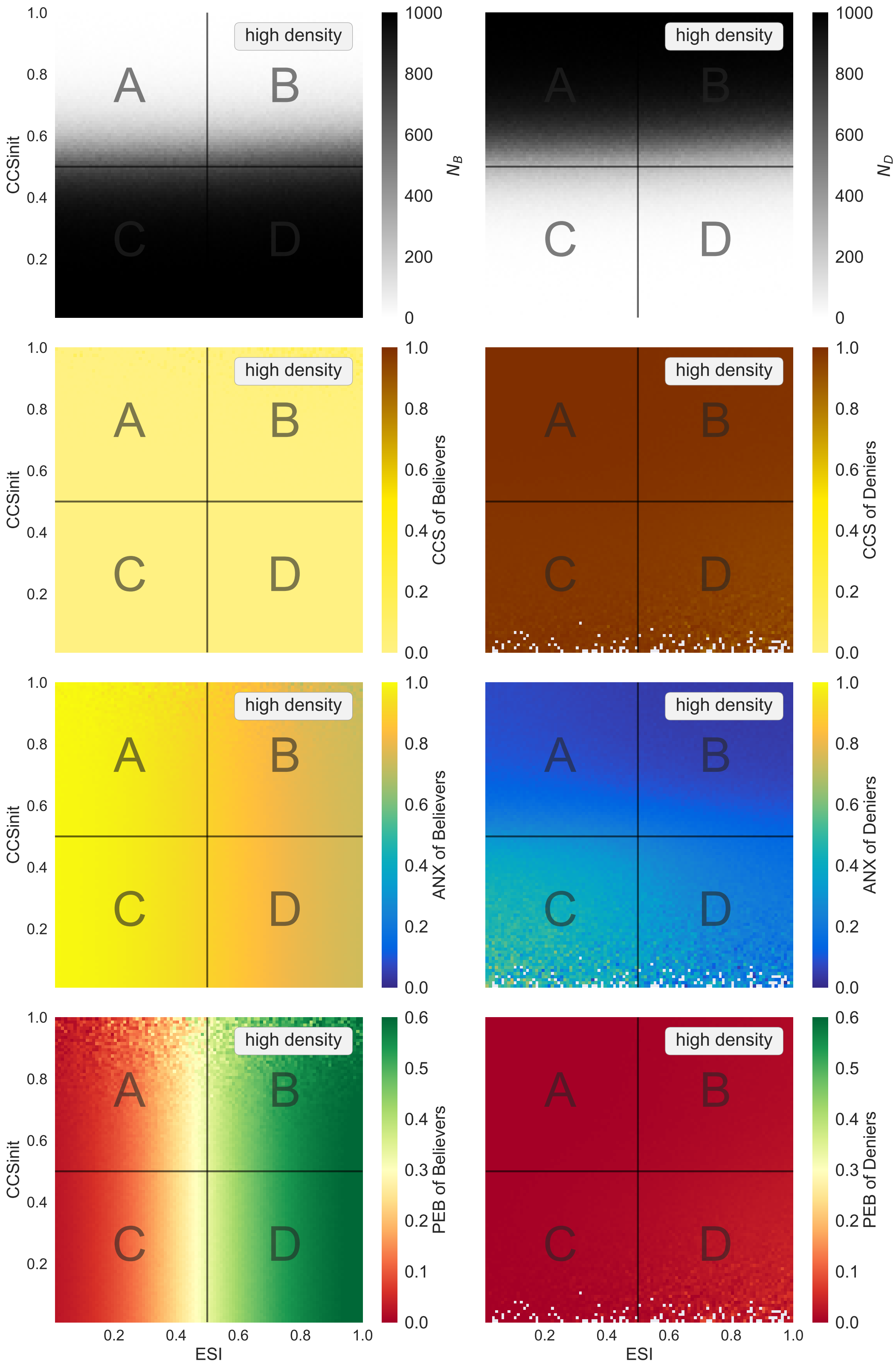

Figure 11. Believers and deniers full parameter plane: Exploration of the initial orientations ESI and $CCSinit$ for the high density case $II = 0.1, IR = 0.1$, (left column) believers and (right column) deniers. Parameter $N = 1000, II = 0.9, IR = 0.9, T = 2000 - 10000$.