Induced Social Behavior: Can Path Dependence or Climate Change induce Conflict?

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To my family

"One finds limits by pushing them."

Herbert Simon

"In order to be a perfect member
of a flock of sheep, one has to be, foremost, a sheep."

Albert Einstein

"Intelligence is the ability to adapt to change."

Steven Hawking

"The best way to predict your future is to create it."

Abraham Lincoln

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List of abbreviations

ABM	Agent-Based Model, Agent-Based Modeling
ACLED	Armed Conflict Location and Events Dataset
ASA	American Sociological Association
CliSAP	Excellence Initiative “Integrated Climate System Analysis and Prediction”
CLISEC	Research Group Climate Change and Security
DFG	Deutsche Forschungsgemeinschaft
GIS	Greenland Ice Sheet
GSDP	Global Systems Dynamics and Policy
IPCC	Intergovernmental Panel on Climate Change
ISA	International Sociological Association
OSAM	Opinionated, Sensitive, Acting Man
PDSN	Path-dependent Social Network
PRIO	Peace Research Institute Oslo
RREEMM	Resourceful: Restricted, Expecting, Evaluating, Maximizing Man
SCAD	Social Conflict in Africa Database
SEU	Subjective Expected Utility
SFI	Santa Fe Institute
SHE	Swarming and Herding agents affected by an Environment
SICSS	School of Integrated Climate System Sciences
SPEED	Social, Political and Economic Event Database
SRSM	Socialized, Role-playing, Sanctioned Man
UDCP	Uppsala Conflict Data Program
US	United States of America
YRNCS	Young Researchers Network of Complex Systems

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Summary

Induced social behavior: Can path dependence or climate change induce conflict?

Social behavior is a complex subject, especially in the context of climate change. Why do people not just change their greenhouse gas-emission behavior from high emissions to low emissions? This can be explained by path-dependent behavior.

This cumulative dissertation shows mathematically sociologically that path-dependent behavior is not only a persistent experienced or standardized behavior. Instead, path dependence can induce a following behavior so that people who allow the induction by path dependence to occur increasingly tend to follow others or the masses in their actions or opinions.

Using social network theory to construct the so-called path-dependent social network (PDSN), it can be shown that path dependence reinforces itself while reducing the number of the used decision alternatives. Agent-based modeling is applied to simulate what kind of dynamics path dependence induces in a group of path-dependently acting agents: path-dependent dynamics. What initially appears intuitive is now logically rigorously "proven" by means of Mathematical Sociology.

Can path dependence induce conflict? The answer is both: yes and no: The purely path-dependent dynamics as presented in the agent-based model, the *SHE-Model*, rather lead to consensus: the bottom-up hierarchies created by the following behavior do not need coercive power structures to enforce obedience. However, people who do not directly allow any induction by path dependence of the same process may rather react in a conflictive manner or evoke conflict in confrontations with the group of path-dependently acting persons.

Can climate change induce conflict? Again, the answer is both: yes and no: The comparative literature review shows unanimous results. While long-term historical studies show a positive relationship between climate change and conflict, more recent studies are not so clear about this link. Considering water treaties, so far cooperation succeeds at the international level. But

climate change seems to work as a threat multiplier: in regions with double exposure – thus with present conflicts and being prone to climate change – climate change aggravates existing conflicts. In the review, this is explained by a high vulnerability of the affected population with a relatively low adaptive capacity, which is already weakened by the prevailing conflict.

Using path dependence in an analytical framework, which shows interactions of the climate system, the environmental system, human security, and societal stability, a path-dependent process can be visualized, which is induced by climate change and self-reinforcing conflict. Discussing the physical and human path dependence that induces and reinforces climate change the question arises: what can climate change and path dependence induce jointly?

Path dependence reinforces the existing conflict or consensus: In a peaceful region, path dependence rather increases the consensus when the population is confronted with climate change events. But as described, path dependence can also reinforce conflicts that are triggered by climate change, which may further increase because of mass dynamics forming in swarms or hierarchies. But even in peaceful regions climate change can increase the likelihood of aggression. And even single events of violent aggression can cascade through path-dependent social networks and involve larger groups of people in a conflict with a further potential to escalate with increasing induction by climate change.

All in all, the explanatory power of a large-scale societal path dependence can be used to find new mitigation or adaptation strategies to alleviate climate change or at least the societal effects of climate change such as potential climate change induced conflict.

Zusammenfassung

Induziertes soziales Verhalten: Können Pfadabhängigkeit oder Klimawandel Konflikte induzieren?

Soziales Verhalten ist ein komplexes Thema, insbesondere im Kontext von Klimawandel. Warum ändern die Menschen ihr Treibhausgasemissionsverhalten nicht einfach, von vielen Emissionen hin zu wenigen Emissionen? Dieses kann durch pfadabhängiges Verhalten erklärt werden.

In dieser kumulativen Dissertation wird mathematisch soziologisch gezeigt, dass pfadabhängiges Verhalten nicht nur von Persistenz oder Standards geprägt ist. Darüber hinaus kann Pfadabhängigkeit ein Folgeverhalten induzieren, so dass Menschen, die den Einfluss von Pfadabhängigkeit zulassen, zunehmend die Tendenz aufweisen, anderen in ihren Entscheidungen zu folgen, egal ob einzelnen Akteuren oder der Masse.

Unter Verwendung der Theorie sozialer Netzwerke werden sogenannte Pfadabhängigkeitsnetzwerke (PDSN) konstruiert, mit denen gezeigt werden kann, dass Pfadabhängigkeit sich selbst verstärkt und währenddessen zunehmend die Zahl der Handlungsalternativen reduziert. Agentenbasierte Modellierung wird verwendet um zu simulieren, welche Art von Dynamiken Pfadabhängigkeit in einer Gruppe pfadabhängig handelnder Akteure induziert: pfadabhängige Dynamiken. Was anfangs vielleicht intuitiv klar zu sein scheint, ist nun rigoros logisch durch Mathematische Soziologie „bewiesen“.

Kann Pfadabhängigkeit Konflikte induzieren? Die Antwort lautet sowohl ja als auch nein: Die rein pfadabhängigen Dynamiken, wie sie mit dem agentenbasierten Model, dem *SHE-Model*, analysiert werden, induzieren vielmehr einen Konsens, denn die bottom-up-Hierarchien, die durch das Folgeverhalten entstehen, brauchen keinen Gehorsam zu erzwingen. Jedoch können Menschen, die nicht direkt den Pfadabhängigkeitseinfluss des gleichen Prozesses zulassen, konfliktiv reagieren oder Konflikte hervorrufen, wenn sie sich mit einer Gruppe pfadabhängig Handelnder konfrontiert sehen.

Kann Klimawandel Konflikte induzieren? Wieder ist die Antwort ja und nein: Die vergleichende Literaturübersicht zeigt uneinheitliche Ergebnisse. Während historische Langzeitstudien einen positiven Zusammenhang zwischen Klimawandel und Konflikt nachweisen, gelangen Studien mit aktuellerem Zeithorizont zu uneinheitlichen Ergebnissen. Betrachtet man beispielsweise Wasserabkommen, so siegt bisher international stets die Kooperation. Aber Klimawandel scheint als Risikoverstärker zu wirken: In Regionen mit doppeltem Gefährdungspotential – also durch bereits existierende Konflikte und eine klimawandelexponierte Lage – verstärkt Klimawandel die laufenden Konflikte. In der Literaturübersicht wird dieser Effekt durch eine hohe Vulnerabilität der betroffenen Bevölkerung erklärt, die eine geringe Anpassungsfähigkeit aufweist, da sie bereits durch die bestehenden Konflikte geschwächt ist.

Unter Verwendung von Pfadabhängigkeit kann in einem analytischen Forschungsrahmen, der die Interaktionen von Klimasystem, dem Umweltsystem, menschlicher Sicherheit und sozialer Stabilität berücksichtigt, ein pfadabhängiger Prozess veranschaulicht werden, der von Klimawandel induziert wird und Konflikte selbst-verstärkt. In der Diskussion der physikalischen und menschlichen Pfadabhängigkeit, die Klimawandel induziert und immer wieder verstärkt, kommt die Frage auf: Was können Klimawandel und Pfadabhängigkeit zusammen bewirken?

Pfadabhängigkeit verfestigt Existierendes, Konflikte oder Konsens: In einer friedlichen Region verstärkt Pfadabhängigkeit eher noch die Einigkeit, wenn die Bevölkerung von Klimawandel betroffen ist. Aber wie beschrieben, kann Pfadabhängigkeit auch klimawandelinduzierte Konflikte verstärken, was noch zusätzlich durch Gruppendynamiken, die sich in Schwärmen oder Hierarchien finden lassen, unterstützt werden kann. Doch selbst in friedlichen Regionen kann Klimwandel die Wahrscheinlichkeit eines Auftretens von Aggressionen erhöhen. Und sogar einzelne Vorfälle von körperlicher Aggression können durch Pfadabhängigkeitsnetzwerke kaskadieren und eine größere Gruppe in einen Konflikt verwickeln – mit weiterem Eskalationspotential, das durch Klimawandel angeheizt wird.

Zusammengenommen kann die Erklärungsstärke einer weitreichenden gesellschaftlichen Pfadabhängigkeit dafür verwendet werden, neue Strategien der Mitigation oder Adaption zu enwickeln, um den Klimawandel zu verringern oder zumindest die gesellschaftlichen

Auswirkungen von Klimawandel zu reduzieren, wie z.B. das Potential klimawandelinduzierter Konflikte.

1 Introduction

> "Human-caused climate change is one of the major problems of our time, and represents an existential threat to our species in the long term. Natural scientists have led the way in documenting global warming, as the "greenhouse effect" was understood over a century ago. By the 1990s climate science had become a well-established field, producing ever-stronger evidence that the world is warming due in large part to human activities (especially carbon emissions), with increasingly negative impacts on both natural and social systems – as documented periodically by the Intergovernmental Panel on Climate Change (IPCC).
>
> In the face of woefully inadequate societal response to growing evidence of global warming, especially in terms of reducing carbon emissions, natural scientists have recognized that climate change is a "people problem": it is caused by human behaviors, it poses real threats to humans, and it requires collective action for its amelioration. Consequently, the IPCC, US National Research Council and other major scientific bodies such as the International Social Science Council and its International Human Dimensions Program on Global Environmental Change (succeeded by the Future Earth Project) have called for greater involvement of social science in climate change research" (Dunlap & Brulle, 2015b).

Is social behavior predictable? At least not in a forecasting sense because as soon as you told a specific person about his or her behavioral forecast, normally every person would act differently on purpose. But still, sometimes people act predictably when following their habits or daily routines (Giddens, 1984), doing the same as their best friends, queuing in front of the bathroom or at a check-in, asking their computer expert for help (Simon, 1983), or following the masses hoping for swarm intelligence (Surowiecki, 2004). Is such behavior stupid? Usually not, as it is generally efficient that our brain does not need to compute all possible actions for each specific situation in life again and again. But sometimes such behavior may not work. One example is the changing environment. If the environment changes, people very

likely need to adapt to the new conditions because their old behavior may not be applicable anymore.

> "This kind of public sociology on climate change involves documenting the difficulty (if not impossibility) of achieving significant reductions in carbon emissions while maintaining traditional patterns of economic growth – sociological findings that can broaden public debates over climate policy. Creating intellectual space for more critical perspectives on climate change should be a crucial contribution of our discipline, and we hope that sociologists worldwide will join the ASA Task Force in this effort" (Dunlap & Brulle, 2015b).

This dissertation contributes to the effort of the American Sociological Association (ASA) Task Force by advancing path dependence theory to explain induced social behavior – behavior that seems impossible to change when allowing for induction. Even though people could theoretically act differently, as soon as they were told what their behavioral forecast would be, nothing – or at least not enough – happens as can be observed in the case of collective carbon emissions. Paul A. David (1985) suggests that agents, even though they are free to choose, act according to the impacts of historical events:

> "The agents engaged in production and purchase decisions in today's keyboard market are not the prisoners of custom, conspiracy, or state control. But while they are, as we now say, perfectly 'free to choose,' their behavior, nevertheless, is held fast in the grip of events long forgotten and shaped by circumstances in which neither they nor their interests figured" (David, 1985).

Consequently, David suggests that historical events induce present behavior. The theory Paul A. David and his colleague W. Brian Arthur (1994) coined is path dependence theory. David focuses on the historical trace that connected events, or – in the case of the QWERTY-keyboard – technical products leave on their way when inducing today's behavior. However, Arthur (1994) rather focuses on the potential impacts of positive feedbacks on market behavior. When trying to predict winners or losers on markets, Arthur discovers that the fundamental mechanism of increasing returns shapes market outcomes. Thus, the mechanism

of increasing returns shapes product sellers' and product buyers' behaviors, which can then be monitored in an aggregated way as the winning or losing of product shares in a market. But if on the one hand specific events may induce behavior and on the other hand a positive feedback mechanism induces behavior, where is the connection? The connection is described by path dependence theory. The definition of path dependence used in this thesis is:

A path-dependent process is a self-reinforcing process
with the tendency towards a lock-in.

In this definition, path dependence is a characteristic of a given process. Does this characteristic already induce social behavior? And if so – how? And what dynamics can evolve? These are the fundamental research questions in this thesis, which I address to advance path dependence theory. As described above, a special challenge for persistent behavior can be the situation of change, particularly environmental change. Therefore, I have chosen the context of climate change as an application of the traditional and the advanced path dependence theory. For climate change itself, there is a debate on whether or not it induces conflict or rather fosters cooperation (see chapters 2 and 3). This potential causality is referred to as the climate-conflict nexus. Thus, based on the state of the art of research on the climate-conflict nexus it can be asked, what role path dependence plays in the potential causality of induction. Does path dependence itself induce conflict? Or does instead path dependence rather induce consensus? Is climate change path-dependent? And what does climate change and path dependence induce together: conflict or consensus?

The current state of research and needs for further studies with regard to the overall subject of this dissertation are outlined in section 1.1. Even though social behavior is a fundamental sociological topic, there is not much literature on "induced social behavior". However, its sociological context is described at the beginning of the theoretical background (section 1.2). The main part in this section is the theoretical background of path dependence and an overview of conflict theories that are applied subsequently to answer the research questions whether conflict can be result of the induction by path dependence or climate change or both. In contrast to conflict, Habermas' consensus theory is briefly described for later application. This is only one mentioned in this context because there are not so many consensus theories as conflict theories.

The methodology used in this dissertation and especially in this general introduction of the cumulative dissertation is described in section 1.3. The principal methodology is mathematical sociology, which I have extended for the applications in this dissertation and especially this introduction. Moreover, the methodology for the basis of the discussion of the climate-conflict nexus is briefly mentioned as well.

The methodologies are applied in section 1.4. The main part of the application is the extension of the path dependence theory using the advancements of mathematical sociology. Section 1.4.1 is based on the chapters 4 through 7, which have already been published separately or have been submitted for publication. Sections 1.4.1.6 and 1.4.1.8 discuss whether path dependence can induce consensus or conflict based on the innovations in path dependence theory (sections 1.4.1.1 through 1.4.1.5, and 1.4.1.7) and the consensus and conflict theories (which are presented in section 1.2.2). Section 1.4.1.7 addresses the question of how many people are likely to actually act path-dependently, and how relevant the abstract development of path dependence theory is for real life. Section 1.4.2 summarizes the findings of the publications on the climate-conflict nexus (chapters 2 and 3). Furthermore, section 1.4.3 presents an additional theoretical advancement, in this overall introduction of the cumulative dissertation ,which states that climate change can induce a path-dependent process that in turn self-reinforces conflict.

The discussion in section 1.5 initially focuses on the general question whether climate change is path-dependent (section 1.5.1), analyzing the underlying processes of physical path dependence (section 1.5.1.1) and of human path dependence (section 1.5.1.2), which both reinforce climate change. The subsequent section 1.5.2 consequently discusses whether path dependence and climate change jointly induce conflict or rather consensus.

In the conclusion (section 1.6), the results of the introduction are summarized, followed by a paragraph of concluding remarks.

The introduction to this cumulative dissertation ends with short summaries of each of the subsequent chapters (section 1.7), which have already been published or submitted for publication.

1.1 State of the art and research needs

In addition to the overall question of (1) induced social behavior the research questions addressed in this dissertation are (2) can path dependence induce conflict? And (3) can climate change induce conflict? To be able to analyze each of these questions, the status quo in research is briefly described here:

(1) Induced social behavior

> "While the fact of social influence is beyond doubt, we are only on the threshold of understanding the responsible processes" (Asch, 1956).

Interestingly, there is hardly any sociological literature on "induced social behavior". Instead, the inductive impacts of drugs on humans or animals are studied in psychology or biology, which potentially induce social behavior. However, in classic sociology agency is considered to be a purposeful action, ideally after weighting different norms or values (cf. e.g. Weber). Furthermore, behavior that is determined by rule-based behavior or social behavior resulting from organizational dynamics are rather interpreted to be enforcements of power structures than the subtle induction of following behavior. In a more general sense, Giddens' duality of structure – where structure is both means and ends of action (Giddens, 1984) – allows for an indirect effect of structure on action. But even there the purposefulness is included because social structure is also ends of action, which implies that a social agent can purposefully create social structures as means to impact future actions. Functionalism does also imply indirect effects of structure but functionalists avoid the terminology of a certain subject taking action and thus would not consider social behavior as such.

However, there are sociologists who see the necessity for sociology to reach out to other sciences (Ellis, 1977) and further advance sociology to not only consider purposeful action, as in other early sciences, but to consider also reductionist approaches, non-purposive behavior and evolutionary dynamics (Ellis, 1977). So far, there are examples in psychology or biology of research on non-purposive behavior (e.g. Abel, 1975; Rincón-Cortés & Sullivan, 2016; Siegel & Poole, 1969), in evolutionary biology of studies on evolutionary dynamics as well, and in mathematical sociology on building agent-based models using evolutionary game theory or neuronal network simulations (Edling, 2002).

> "Mathematical sociology is not an oxymoron. There is a useful role for mathematics in the study of society and groups. In fact, that role is growing as social scientists and others develop better and better tools for the study of complex systems. A number of trends are converging to make the application of mathematics to society increasingly productive" (Bonacich & Lu, 2012, p. 1).

In this dissertation mathematical sociology and agent-based models are used as well as the perspective of social network theory. All these methods I apply to deduce a new advanced path dependence theory to address induced social behavior.

(2) Can path dependence induce conflict?

The general path dependence theories do not explicitly consider an induction of behavior but rather consider the result of it: the identical actions in consumer behavior when jointly selecting a winner on the market (Arthur, 1994), or the historical sequences of events leading to locked-in products (David, 1985, 2001; Mahoney, 2000) or locked-in practices (Pierson, 2000). Organizational sociologists rather focus on the logics of assuring continuity in a path-dependent process (Beyer, 2005), management sciences emphasize the self-reinforcing mechanisms (Sydow et al., 2009) or emphasize the lock-ins (Schreyögg & Sydow, 2003). But to find a way out of the inability of action in lock-ins, the theory of path creation has been created (Garud & Karnøe, 2001). In the theory of path creation, it is considered that agents involved in organization can initiate change from their position, wherever they are. But they do not use the terminology of conflict in this context. In a way, path dependence theory

induces conflict among researchers because a characteristic associated with path dependence is inefficiency, which the economists do not like (Liebowitz & Margolis, 2014). Starting with the assumption that a process that selects the 'right', respectively the superior, product in a given market does not neglect the general market assumption of the invisible hand, only processes that select a 'wrong' product, a technologically inferior one, would contradict market theory and would be allowed to be called path-dependent. But these are unlikely or – un-liked by economists – to exist as the conflictive debate demonstrates (Liebowitz & Margolis, 2014). In current research also a sense of "dependence-induced conflict" can be found in the context of environmental change, when potentially resource dependence induces conflict (Barnett & Adger, 2007; Elbadawi & Sambanis, 2000; Homer-Dixon, 1994), or structural or strategic dependence induces conflict (Chow, 2014). However, there is no literature on whether path dependence induces conflict yet, which is studied in this dissertation.

(3) Can climate change induce conflict?

In our publication in *Science* called "Climate Change and Violent Conflict" (chapter 2 of this dissertation) we state that since the publication of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the debate has intensified, referring to reviews (Bernauer et al., 2012; Buhaug & Theisen, 2012; Gleditsch, 2012; Scheffran et al., 2012a), but remains controversial (chapter 3 of this dissertation). As a reaction to our publications a clear statement has been published quantifying the linkage between climate change and violent conflict by American colleagues: "Each 1-SD change in climate toward warmer temperatures or more extreme rainfall increases the frequency of interpersonal violence by 4% and intergroup conflict by 14% (median estimates)" (Hsiang et al., 2013). We, a number of European researchers on climate and conflict, have instantly criticized especially the meta-study design for comparing incomparable studies with mixed definitions, using a couple of studies more than once (when considering different variables) while leaving other more ambiguous studies out for methodological reasons, which can have a significant impact on the computed result (Buhaug et al., 2014).

Further research in this area concentrates on specific regional foci on regions that are presumably vulnerable and prone to climate change, as these are usually areas with a low

adaptive capacity like e.g. Kenya and Uganda (Ide et al., 2014), the Horn of Africa (Solomon et al., 2018), Africa in general (Cabot, 2015), Sub-Saharan Africa (Witmer et al., 2017), Northern Africa (Link et al., 2015), the Middle-East and Northern Africa (Waha et al., 2017), Syria (Selby et al., 2017), or Palestine (Schilling et al., 2017). Others focus on special mechanisms that may lead to conflict such as water issues (Link et al., 2016), water and land (Seter et al., 2018), migration (Missirian & Schlenker, 2017), or gender issues (Omolo et al., 2017). Additional research critically analyzes the debates and data usage such as gendered resilience discourses (Rothe, 2017), reflections on the methods used (Ide, 2017), or sampling bias in climate-conflict research (Adams et al., 2018; Hendrix, 2018).

While none of the above discusses the role of path dependence in the climate-conflict nexus, a paper on resilience emphasizes the value of including path dependence theory in the context of socio-ecological systems:

> "[T]aking institutional change dynamics seriously by moving away from assumptions about institutions as static and linear has the potential to contribute greatly to the understanding of social-ecological systems. As recognized by Anderies et al. (2006:867), taking path-dependent dynamics into account "adds considerable value by capturing institutional and social constraints to management action typically not considered." For instance, this would potentially help resilience thinking further understand […] the underlying self-reinforcing mechanisms sustaining, and even strengthening, particular institutional arrangements […]" (Sjöstedt, 2015, p. 3).

In this thesis, I advance path dependence theory to consider path-dependent dynamics based on path-dependent behavior induced by path dependence. Furthermore, I use the advanced path dependence theory to connect path dependence theory and neo-institutionalism, particularly focusing on the self-reinforcing process of institutionalization. When analyzing the climate-conflict nexus, I discover and visualize a path-dependent process in a complex analytical framework, which is self-reinforcing conflict triggered by climate change. Furthermore, I discuss the potential influence of path dependence in the climate-conflict nexus based on the path dependence theory advanced in this dissertation.

1.2 Theoretical background

As described, I have drawn the question of induced social behavior from path dependence theory. Focusing on a person practicing social behavior, how is he or she potentially influenced in doing so but still free to choose without any external force?

In this dissertation I use mathematical sociology to assess the question whether path dependence, the characteristic of a process, can already induce social behavior in a general sense without considering a specific topic or situation. Then I deduce whether path dependence induces conflict or consensus and what characterizes the behavior in the one or the other direction. Furthermore, I review whether climate change can induce conflict – which is considered as a specific type of social behavior here – and discuss how this interacts with inductions by path dependence. Thus, for the further work path dependence theory as well as conflict and consensus theory are needed. These are presented in this section of theoretical background.

1.2.1 Path dependence theory

There are many ways to present path dependence theory from various perspectives, in different contexts and disciplines. In this dissertation, chapters 4 through 7 also each include a description of path dependence theory. Chapter 4 presents path dependence theory from a multi-level problem-solving perspective and how useful which of the main approaches could be, pointing to the necessity for a path dependence theory of agency, which is then created in a new model frame. Chapter 5 presents path dependence theory from a perspective of social networks and cascades, creating path-dependent social networks (PDSN) as a tool to explain trans-regional and trans-sectorial cascades. Chapter 6 presents path dependence theory in a mathematical sociological approach, seeking to extract an abstract causality that can be used to explain and understand path-dependent dynamics in various contexts, generating and using an agent-based model of swarming and herding agents affected by an environment (*SHE-Model*). Chapter 7 uses path dependence theory in an even more abstract way in a

mathematical sociological proof of the linkage between neo-institutionalism and path dependence theory, focusing on self-reinforcing processes and the process of institutionalization.

In addition to these perspectives on path dependence theory presented in the separate chapters later-on, path dependence theory is presented here from the perspective of induced social behavior, for which the cited literature is clustered in three substantially different ways of interpreting path dependence: history matters, persistence, and the butterfly effect. Furthermore, the question of agency is raised, which is not new in path dependence theory but which is fundamental for considering social behavior induced by path dependence.

1.2.1.1 History matters

"History matters" is a very general approach in path dependence theory that emphasizes the sequence of events and that the chronological order has an effect on the final outcome. In the case of the QWERTY-keyboard (David, 1985), even though former arguments of clashing or jamming of early typewriter's keys are no longer applicable with modern computer keyboards or even smartphones, the placement of letters on the "keyboard" remains the same. If somebody changed the order of letters, it would likely be considered to be a mistake rather than considered as change. This understanding of path dependence supports the idea of induced social dynamics because the induction follows a timeline with the initial event as cause and the induced social dynamics as consequence. Accordingly, the induced social dynamics happen chronologically after the initial event and this process would not work the other way round. Of course, the induced social dynamics could be considered a new starting point triggering further effects moving forward in timeline. But here the focus is on the induced social dynamics.

When David (1985) narrates the story of the QWERTY-keyboard, he first defines a path-dependent sequence in stochastic terms describing that history matters:

> "A *path-dependent* sequence of economic changes is one of which important influences upon the eventual outcome can be exerted by temporally remote events, including happenings dominated by chance elements rather than systematic forces. Stochastic processes like that do not converge automatically to a fixed-point distribution of outcomes, and are called *non-ergodic*. In such circumstances "historical accidents" can neither be ignored, nor neatly quarantined for the purpose of economic analysis; the dynamic process itself takes on an *essentially historical* character" (David, 1985, highlights as in the original document).

David's "story", as he calls it, is about the QWERTY-keyboard (the starting letters in the first row on the keyboard QWERTYUIOP), why it has been designed like that on traditional type writers followed by a road of success even though a more efficient keyboard layout has been available all the time. David's explanation is path dependence. Economists have immediately countered the interpretation of David's story of the market failure by path dependence (Farrell & Saloner, 1985; Garud & Karnøe, 2001; Katz & Shapiro, 1986). They deny the existence of path dependence and the relevance of the concept presenting additional economic arguments on why the sunk costs have been higher than estimated by David and that the economic value of learning effects makes a switch to an alternative technology, rationally decided, too costly.

Many scholars have taken up the story and the debate (summarized by Beyer, 2005, 2015; Liebowitz & Margolis, 2014; Mahoney & Schensul, 2006; Vergne & Durand, 2010). Kay (2013) has even simulated and historically reanalyzed the previous arguments for the early market decisions for the QWERTY-keyboard, concluding that the technology has rather been superior than inferior, which counters the idea of market failure. But Arthur (2013) replies: "The onus is not on Paul David to show that QWERTY was inferior to one possible keyboard, Dvorak. The onus is on his critics to show that QWERTY is superior to all other possible keyboards. I calculate that there are 2,658,271,574,788,448,768,043,625,811,014,615,890,319,638,527,999,999,999 of these, an admittedly large number (some 10^{54})." To Arthur, the most important aspect is the problem that David has pointed out in historical economics of potentially inferior technologies locked in a dominant position in a given market, which no longer could be considered to be functioning anymore in always selecting the best. Instead, history matters.

> "QWERTY, as a standard – or better as an example of what the market has served us up in the long evolution of one particular technology – has become in economics a focal point, a rallying point for a larger issue: whether the market can lock us into an inferior standard. And this itself is part of a still larger issue: whether the free markets of capitalist economies can drive us into inferior outcomes" (Arthur, 2013, p. 1186).

The theory has been further developed for example by Mahoney (2000) on reactive sequences, by Pierson (2000) on applications in political sciences, by Page (2006) on stochastic processes, and by Pfau-Effinger (2008) applied to welfare states.

1.2.1.2 Persistence versus path breaking

Persistence is the second understanding of path dependence: No matter how the path-dependent process started, self-reinforcing mechanisms stabilize the process towards a lock-in. At the beginning of the path-dependent process, it is not determined when or in which situation the lock-in is reached (i.e. who wins?) (Arthur, 1989, 1994). But the tendency towards a lock-in is embedded in the definition of a path-dependent process (Sydow et al., 2009). In the situation of a lock-in, change happens only incrementally (North, 1990) if it occurs at all. Accordingly, induced social dynamics are dampened out by the lock-in or they also happen only incrementally. Alternatively, induced social behavior can move the path to a different level or even break the lock-in and accordingly break the path (Garud & Karnøe, 2001). "They [Insiders] are able to develop the generative impulse required to commit themselves to an initiative and, in the process, enact their environments (March & Olsen, 1998; Weick, 1979)" (Garud & Karnøe, 2001, p. xii).

1.2.1.3 The butterfly effect

The butterfly effect is a third understanding of path dependence. The dynamic it describes is that the flap of a butterfly in China may subsequently cause a hurricane in Florida (Lorenz,

1963). In social sciences, this metaphor has been used to describe the complex phenomenon of tiny events having large effects (Gregersen & Sailer, 1993). The mechanism of increasing returns (Arthur, 1994; Pierson, 2000) can lead to significant impacts of tiny events over time.

One example is the effect the Fukushima disaster had on the political shift towards renewable energy production in Germany. It can be explained via cascading effects in social networks (chapter 5). Thus, via path-dependent social structures an initial event can induce social dynamics in geographically far distant regions.

1.2.2 Conflict and consensus theory[1]

The dispute between a conflict theory and a consensus theory has profoundly shaped sociological theorizing: consensus theories rather tend to preserve the status quo while conflict theories urge societies to change (cf. Bernard, 1957; Imbusch, 1999; Senghaas, 1969). While path dependence in its understanding as history matters or its effect of assuring persistence rather seems to preserve the status quo, climate change may rather urge society to change when potentially inducing conflict. Aggression theory can help explain the potential direct environmental effect on a person's behavior. Potential resource conflicts that may be induced or enhanced by climate change can be explained by opposing values or aims in a rational choice theoretical background. Furthermore, it is important to focus on agency and action theory when considering whether or not conflict can be induced social behavior. In addition to this conflict theoretical background, consensus theory will also be discussed as basis for subsequent explanations of cooperation, conformity, or persistence, and a potential unwillingness to change the status quo.

1.2.2.1 Conflict theory

Conflict is one of the fundamental terms in sociology. The definition of the term conflict depends on the perspective and theoretical background of the respective sociologist and the

[1] While other parts of this dissertation are more in detail, this mentioning of conflict theories only scratches the surface. The main emphasis in this dissertation lies on the deduction of path dependence-induced behavior and climate change-induced behavior as well as on path dependence in the climate-conflict nexus, whereas conflict is only one possible classification of the potentially resulting dynamics.

context, in which the term conflict is applied. While the sociology of conflict can be structured along the lines of the following three discourses, only the first and the third are presented in the subsequent section focusing on aggression theory and rational choice theory:

- biological determinism - defining a sociology on the basis of the destructive tribes of the animal human, determined by his genes and the evolutionary selection
- social theory focusing on social structure or social values – describing conflict as result of communication in a social system, structural contradictions or opposing values
- interaction and action theory – interpreting conflict among social actors as basis for societal change

1.2.2.1.1 Aggression theory - man in nature

Conflict exists where in the absence of order there is awareness that society needs to order itself. Many philosophers and sociologists have asked themselves what it implies if people are considered as human animals in nature in the absence of social or governmental structures, purely lead by their instincts and genes. For Hobbes, the naturally destructive interaction is the basis of social conflict. Hobbes' consideration of the fundamental fight of "all against all" leads to the social contract, in which people give up some liberties in order to enjoy peace. Through this thought experiment, a sovereign state is legitimized to govern the natural drivers to reduce their destructive impact and to guarantee social order[2].

"People sometimes react to aversive conditions just as animals do. Moreover, in human beings, as in other animal species, an impressive variety of unpleasant events can provoke aggressive behavior" (Berkowitz, 1993, p. 51). In aggression theory, a kind of impulsive behavior is described that can be partly explained by environmental influences.

[2] Modern theories use biological thinking as well, for example, when considering evolutionary or genetic algorithms. Applying mechanisms that can be observed both in animal behavior and in human behavior does not necessarily imply the general assumption of humans being an animal because they act like one. But the concept of sociobiology is based on the idea that humans act like animals because of their evolution (Darwin), which has selected their current genes that determine them and their behavior. Of course, this sociobiological perspective cannot explain real social interaction because it finally explains all actions as internally determined via one's own genes.

> "Take high temperatures as a case in point. Have you ever found yourself in a very hot room that you couldn't leave for several hours, for one reason or another? If you're like many other persons, according to a growing body of research, there's a good chance that you became irritable and perhaps even openly hostile" (Berkowitz, 1993, p. 51).

Especially, the neoassociationistic aggression model by Leonard Berkowitz as a revision and development of the classical frustration-aggression-theory includes the consideration of an environmental component (Bonacker, 2008). Therefore, it is interesting for the application in the context of climate change-induced conflict. But first a general definition of aggression:

> "The term 'human aggression' characterizes - at least from the point of view of the person affected or a neutral judge - an inconsiderate or malicious violation of a norm which implies current or potential harm by a person actively responsible; characterizing the violation of the norm as 'inconsiderate' or 'malicious' implies that no arguments for exonertion (e.g. excuses or justifications) will be accepted" (Mees, 1990, p. 286).

It is important to note that aggression in this case is a behavior, not a feeling, judged by an observer or affected person and not by the actively responsible person. 'Inconsiderate' in this definition implies that the harm is not the end of the action but rather a means towards some other goal, whereas aiming at something does not imply a previously rational decision-making process. 'Malicious' refers to the harm that is the end of the action. In his neoassociationistic aggression model, Berkowitz (1993) only considers 'malicious', not 'inconsiderate' human aggression. Thus, it is just some influence and the act of the aggression that counts, not any implied goal.

The original frustration-aggression-theory states that every frustration leads to aggressive behavior and every observable aggressive behavior is the result of a frustration (Dollard et al., 1939). However, in Berkowitz' neoassociationistic aggression model not every frustration leads to aggression (empirical studies have contradicted the direct causality) but rather an

interplay of emotions and cognition leads to aggressive or non-aggressive behavior after a frustrating event.

> "The event itself obviously arouses negative affect, and theoretically, presumably because of our biological 'programming', the unpleasant feeling gives rise automatically to a variety of expressive-motor reactions, feelings, thoughts, and memories. Some of these are associated with fight tendencies - that is, with the inclinations to attack someone (preferably but not only the perceived source of the felt unpleasantness) - while other reactions (which occur at the same time) are linked to flight reactions - to the inclination to escape or to avoid the aversive situation" (Berkowitz, 1993, p. 57).

With regard to the neoassociationistic aggression model, negative environmental conditions can cause or influence the likelihood of choosing anger (related to fight) as an interpretation more often than fear (related to flight) (Bonacker, 2008). Thus, environmental changes can cause these feelings or increase the likelihood of their occurrence, if they create events that may trigger frustration. The own affectedness and feeling bad in addition to the potentially unequal affectedness compared to others within reach can evoke aggression or release it on others within reach who may or may not be affected or responsible for the considered person's bad feelings. The larger the environmental changes and the worse the considered person is feeling, the lower the threshold to actually perform aggression and violence on others becomes. If weapons are present, they increase the likelihood for the considered person to interpret his or her own feelings as anger, which increases the likelihood to act aggressively (Berkowitz, 1993, p. 72ff.). Thus, existing conflicts can increase the likelihood of further aggression even if such aggression is not directly related to the existing conflict constellation. Vice versa, aggressive behavior can induce further conflicts and enhance existing ones.

1.2.2.1.2 Interactionism and action theory

In this discourse, the focus is on an individual level beyond social structure concluding from social actors and their relations to society as a whole. Georg Simmel is a sociological classic for this action theoretical perspective. To Simmel, conflict is important for the integration of

people in groups, and as such conflict is no danger for society but just collectivization. Based on Simmel, in modern sociology Lewis A. Coser has described conflict as necessity for social change because of its socializing character: Conflicts lead to adjustment or recreation of social norms and rules, new social structures are built and within the onset of conflict involved persons become aware of the rules.

Furthermore, there are many action theories on conflict. Within sociological theory, for example Mead, Goffmann, and Esser can be mentioned in this context. And also in social psychology and economics many action theoretical approaches can be found that analyze conflicting scenarios: e.g. game theory, which can be seen as a combination of economical and sociological thinking. Even though game theory is based in microeconomics, it is actually an expansion of sociological rational choice theory.

1.2.2.1.3 Rational choice theory as conflict theory

Rational choice theory is a very broad field of sociology at the intersection with economics, seeking to explain every potential social behavior as the outcome of individual interaction that is supposed to be basically rational (Coleman, 1990; Esser, 1993). One fundamental model is RREEMM:

> "Resourceful: man can search for and find possibilities; he can learn and be inventive;
>
> Restricted: man is confronted with scarcity and must substitute (choose);
>
> Expecting: man attaches subjective probabilities to (future) events;
>
> Evaluating: man has ordered preferences and evaluates (future) events;
>
> Maximizing: man maximizes (expected) utility when choosing a course of action;
>
> Man" (Lindenberg, 1985).

RREEMM is a sociological development of the homo oeconomicus, which is a special case of RREEMM. Just as well, Lindenberg (1985) compares RREEMM with two extensions of the homo sociologicus:

> "In terms of an acronym, the homo sociologicus of structural functionalism can be presented as: SRSM. These letters stand for: Socialized: man internalizes role expectations (norms and values); Role-playing: man acts according to situational role expectations; Sanctioned: man is guarded against deviancy by the sanctions of others in case socialization is not perfect; Man.
>
> The homo sociologicus of sociological empiricism can be presented as: OSAM. These letters stand for: Opinionated: man forms an opinion about everything; Sensitive: man's opinion is easily influenced by others; Acting: man acts directly on the basis of his opinions; Man" (Lindenberg, 1985, p. 101f.).

Lindenberg (1985) shows that SRSM and OSAM are also special cases of RREEMM. Within this model thinking on the micro level, actors can be considered as composing their subjective expected utility (SEU) and playing pairwise prisoner's dilemmas, in which even though both would be better off in practicing cooperative behavior, each is better off when defecting and thus the Nash-equilibrium is the situation of both defecting each other, i.e. the situation of conflict (Bonacker, 2008).

To explain conflicting situations when applying rational choice theory, the individual steps in the argumentation are very important (Coleman, 1990): from the situational event (on the macro level), the disaggregation to the micro level, and after the social interaction on the micro level, the aggregation back to the macro level. As an example for these macro- and micro-level propositions, Coleman applies this theory on the effects of improved social conditions on potential for revolution: Improved social conditions on the macro level is disaggregated into the frustration of individuals who would like to have a larger share of the improved conditions. This may result in aggression of those individuals, which can aggregate into a revolution (Coleman, 1990, p. 10). Interestingly, this example shows how closely rational choice conflict theory can be connected to the frustration-aggression theory to explain

a potentially occurring increase in the level of violence. Rational choice theory and the SEU can be applied to explain arms races and resource conflicts (Scheffran, 1989, 2008; Scheffran & Hannon, 2007), too.

1.2.2.2 Consensus theory

Consensus is the opposite of conflict as in the situation of total consensus there is no conflict. But while a conflict theory can be defined based on practically every sociological theory, there are far fewer approaches to define a consensus theory. A very famous one is the consensus theory of truth by the classic Jürgen Habermas. As part of his general theory of communicative competence, Habermas designed the consensus theory of truth to answer the question of how mutual understanding between speakers is possible. Habermas seeks the answer in the virtue of the norms of communicative rationality and defines communicative competence as the implicit knowledge of these norms. But what is 'truth' in the communicative definition? And how is a consensus reached?

> "Habermas's consensus theory of truth is most aptly characterized as a pragmatist theory of truth. Like pragmatist theories, it asserts that the meaning of 'truth' must be given in terms of the means of vindicating claims about the truth of statements (or a truth criterion). Understanding the sense of 'truth', for the consensus theory and for pragmatist theories generally, is knowing what would constitute a decisive ground for affirming or disaffirming an asserted statement. Habermas believes that universal consensus under ideal conditions is the ground or criterion of correct truth claims, and that this criterion constitutes the meaning of 'truth' as the term is used in practice. The truth, then is defined by a consensus theory of truth as that which is agreed on under ideal conditions" (Braaten, 1991, p. 20f.).

Habermas connects his understanding of truth with a class of speech acts, where speakers raise truth claims in making their assertion. He acknowledges that the ability to raise a truth claim requires awareness of and the ability to understand possible demands for its defense

(Braaten, 1991, p. 22). That way, truth is a kind of warranted assertibility. Ideally, this understanding of truth correlates with the outcome of a rational consensus:

> "A rational consensus, a position to which the participants of the consensual group are rationally committed, is reached through discursive argumentation. The discussion comes to a close when all participants are rationally motivated, by the force of the better argument, to accept the outcome. In place of a proof or verification procedure, Habermas defends a pragmatic 'logic' of discourse. Discursive argumentation, the process required for the justification of a truth claim for a statement, follows a pragmatic discursive procedure that divides argumentation into three basic 'modalities': the proof that a claim is absurd or impossible, the proof that a claim is necessarily true (the impossibility of the negation of the claim), and the justification of contingent statements" (Braaten, 1991, p. 23f.).

By means of this theory, Habermas defines a communicative understanding of truth via a consensual agreement, which is ideally based on rational unemotional discursive argumentation, just one by better arguments. The expertise of the relevant speakers shows up in being able to follow the pragmatic discursive procedure in either proving that the truth claim is obviously false or true, or the justification of contingent statements, where the truth is only discovered when a rational consensus can be reached in the debate.

> "Social existence presupposes, we have seen, the achievement of consensus; but consensus, if it is not to be an empty or treacherous gesture, must have validity. The meaning of consensus collapses when individuals act like mirrors that reflect each other" (Asch, 1952, p. 495).

1.3 Methodology: Mathematical Sociology

> "Mathematical sociology weds mathematics and sociology to advance the scientific understanding of social structures and social processes. Within the

> broad arena of sociology, it stands in that corner defined by a generalizing orientation, by the belief that a science of social orders is possible, by a commitment to a logical derivation of empirical regularities from formally stated axioms or assumptions, and by a concern for the integration […] of sociological theory" (Skvoretz & Fararo, 2011, p. 1).

While the debate in mathematical sociology can be generally structured into the topics of social processes (Coleman, 1964), social structures (White, 1963, 1970), and interaction of purposeful actors (Coleman, 1990), approaches in modern mathematical sociology also combine two or more of these perspectives in agent-based models and even drop the assumption of purposefulness in evolutionary game theory models or neural network models (Edling, 2002). Even though aiming for precision (e.g. Hedström & Swedberg, 1998, p. 24), all of these approaches seem to use "proofs" only in the context of pure mathematics.

The following analyses use mathematical sociology when combining an agent-based modeling and a social network approach without the assumption of purposefulness, so they can definitely be placed in modern mathematical sociology. But additionally, mathematical formalization of logical arguments is transferred to advance mathematical sociological theory via mathematical sociological proofs that include not only mathematical reasoning but also sociological theory. Thus, rigorous mathematical sociological reasoning is applied in the typical mathematical structure of a theorem and its proof, using a clear definition to start out with (where possible), considering clearly stated and as few as possible further assumptions, and the application of rigorous logic and causality. That way, sociological thinking can be advanced in a mathematically sociologically rigorous way by combining the mathematical and sociological language – without equations to stay close to the existing sociological theory.

1.3.1 Social networks

One of the largest and presumably most established parts of mathematical sociology in sociology is the topic of social networks. This includes the theory, empirical studying, and analysis of social networks. It is hardly possible to analyze a group of interacting people without including their social relations with each other: Who knows whom? Who talks to

whom? Who goes to the same sports club, is member of the same What'sApp group, or has children in the same school? All of these relationships can be visualized in a social network or even on various layers of interconnected social networks (Padgett & Ansell, 1993). Generally, a social network consists of nodes that represent actors, which can be single persons or social entities such as groups, organizations, companies, or governments, and edges that mark the relationship among these actors. Depending on the context, in which the social network is applied, the connections are also called linkages or ties or can represent transactions.

> "Social network analysis is used widely in the social and behavioral sciences, as well as in economics, marketing, and industrial engineering. The social network perspective focuses on relationships among social entities; examples include communications among members of a group, economic transactions between corporations, and trade or treaties among nations. The focus on relationships is an important addition to standard social and behavioral research, which is primarily concerned with attributes of the social units" (Wasserman & Faust, 1994, p. 828).

Social network analysis largely applies mathematics from the field of graph theory on social cases to enrich empirical analyses or gain theoretical insights for designing a study or testing hypothesis. But it can also be combined with statistics, e.g. when analyzing time series of social relations in empirical data. Furthermore, some sociological phenomena depend upon the underlying structure of the social network, thus assessments of the characteristics of specific social networks can help to come up with generalizations in sociological theory.

Generally, a social network maps the connection between actors. But in a directed social network the linkage can point from one actor to another, which can indicate a hierarchy within the social network, the direction of the flow of information or other transactions. If a social network is only considering the contacts of one single actor who can be called an ego, the social network is called an egocentric network. A social network is called a spatial network when it shows a spatial component, e.g. if it has a geometrical object or geographical component. But also if the network can be simulated in an abstract space such as to show social distance not only via the linkages of the social network but also in a theoretical social space, the analyst of the social network can refer to the spatial distance or spatially

distinctness, which for instance can change over time, within this abstract space. For example, if two persons visit online communication platforms, they might get to know each other no matter where they live or stay at that time. But depending on their online behavior, whether they stick to their communication platform or switch, whether they stick to their peers and follow them if the peers leave, or rather follow the masses to the largest communication platform, their communication with each other can become more or less likely and this likelihood can be visualized as a potentially varying social distance in an abstract space.

A few popular examples of social network research are Barabási's theory of small world networks and Granovetter's theory of the power of weak ties (Granovetter, 1973). Analyzing small world networks, which are networks of a special mixture of clusters and additional linkages among these clusters, Barabási and Albert have indicated that "the development of large networks is governed by robust self-organizing phenomena that go beyond the particulars of the individual systems" and further "[s]imilar mechanisms could explain the origin of the social and economic disparities governing competitive systems" (Barabási & Albert, 1999).

> "Anthony Giddens, one of the most influential sociologists of the 20th century, argued in his theory of structuration that as societies become modernized, the concept of time becomes increasingly independent from space, and subsequently the concept of space becomes independent from place. […] The impact is that someone's social space is increasingly 'penetrated by and shaped in terms of social influences quite distance from them' (Giddens, 1990, p. 19). […] Thus, the small world model could be considered an abstraction for the effects of modernity on social structure" (Bonacich & Lu, 2012, p. 115).

Further research on small worlds can be found e.g. by Kleinberg (2000) and Watts and Strogatz (Watts & Strogatz, 1998), highlighting the importance and relevance of small world networks.

In his theory of the power of weak ties, Granovetter defines the "strength" of an interpersonal tie as: "the strength of a tie is a (probably linear) combination of the amount of time, the

emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie" (Granovetter, 1973, p. 1361). While he undermines his theory with the important characteristic of weak ties to bridge otherwise socially distinct communities, he also indicates that the study of weak ties has usually been excluded in empirical studies up to his publication.

> "The major implication intended by this paper is that the personal experience of individuals is closely bound up with larger-scale aspects of social structure, well beyond the purview or control of particular individuals. Linkage of micro and macro levels is thus no luxury but of central importance to the development of sociological theory. Such linkage generates paradoxes: weak ties, often denounced as generative of alienation (Wirth, 1938) are here seen as indispensable to individuals' opportunities and to their integration into communities; strong ties, breeding local cohesion, lead to overall fragmentation" (Granovetter, 1973, p. 1377f.).

1.3.2 Agent-Based Modeling (ABM)

> "Agent-based models (ABMs) are computer simulations of social interaction between heterogeneous agents (e.g., individuals, firms, or states), embedded in social structures (e.g., social networks, spatial neighborhoods, or institutional scaffolds). These are built to observe and analyze the emergence of aggregate outcomes" (Bianchi & Squazzoni, 2015, p. 284).

The idea of an ABM is to monitor the evolving dynamics within a framework of a fixed set of assumptions such as the number or type of behavior of social agents and perhaps the characteristics of social structures. Even more interesting and insightful are changing micro variables and monitoring the influences they have on macro-level results. That way, ABMs can be used to discover, test, and understand social mechanisms (Hedström & Bearman, 2009; Hedström & Swedberg, 1998; Hedström & Ylikoski, 2010). Early applications of ABMs to discover the potentially large macro effect of tiny micro changes included rational choice models by Coleman (1964) and the segregation models by Schelling (1971, 1978). Through

the years, Coleman's macro-micro-macro model (e.g. Coleman, 1990), also referred to as Coleman's boat (Figure 1), has become a classical representation of indirect conclusions on the macro level that can be deduced from a reduction to the micro level, a further development on the micro level and then an aggregation back to the macro level. In this representation, aggregation can be described and analyzed by ABM. In the preparation of the ABM, first the step of reduction (macro-micro) as background theory for expressing the relevance and legitimization to look at single agents and the description and setup of these agents and their potential interaction (micro-micro) needs to be solved. The result is an ABM (micro-macro) that visualizes macro level phenomena based on micro level assumptions deduced from previous macro level theory or empiricism.

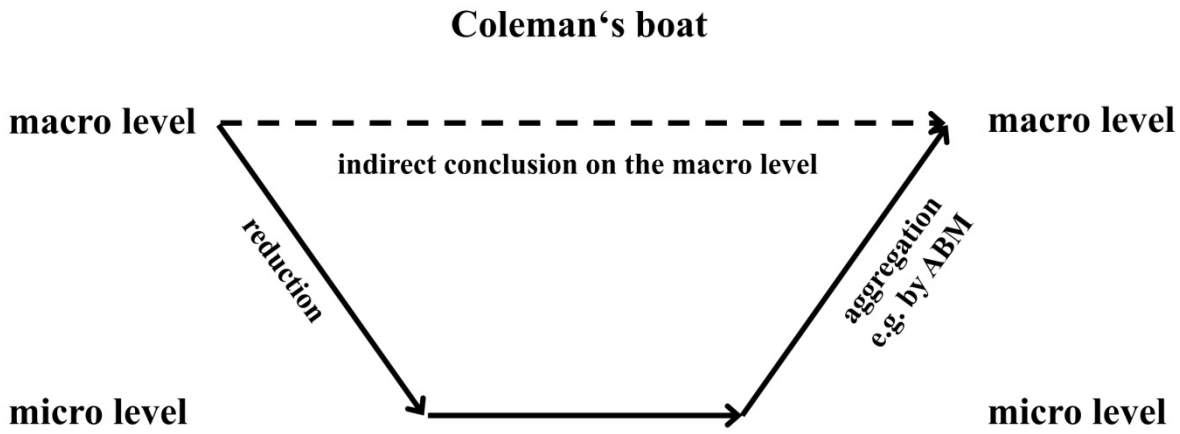

Figure 1 Coleman's macro-micro-macro model, also called Coleman's boat.

Sociological applications of ABM include but are not limited to collective opinions, cooperation and social norms, culture dynamics, diffusion, political coalitions, residential ethnic, segregation, and social influence (Bianchi & Squazzoni, 2015). ABM can also be applied to social networks, e.g. when considering processes of diffusion on a social network like an informational cascade and ABM can include social networks, e.g. in models of contagion. "ABMs prove capable of producing messy contingent outcomes and a range of phenomena: randomness, equilibria both static and distributional, patterns and complexity, and the complex outcomes can vary in their amount and type of path dependence (Page, 2006)" (De Marchi & Page, 2014).

1.3.3 Towards mathematical sociological proofs: q.e.d.s.

Can path dependence induce behavior? If so, how can path dependence induce behavior? Can path dependence induce conflict? If so, how can path dependence affect climate change-induced conflict? All of these questions are research questions in this dissertation in the context of social behavior being affected by path dependence. Answering all four research questions spans a long chain of deductions and causalities.

> "In this paper I shall attempt to show, by means of a concrete example, how mathematization of a body of theory can help in the clarification of concepts, in the examination of the independence or non-independence of postulates, and in the derivation of new propositions that suggest additional ways of subjecting the theory to empirical testing" (Simon, 1952, p. 202).

Therefore, mathematical sociology uses the clarity and explicitness of the mathematical language (Simon, 1952), which can help to dissect the effects of path dependence on social behavior, to re-aggregate potential dynamics while simulating the further influence of path dependence, and to apply these theoretical developments on the topic of climate change-induced conflict in the context of sociological conflict or consensus theories.

> "Mathematics provides a battery of languages which, when carefully fitted to a set of ideas, can lend those ideas great power. The mind falters when faced with a complex system or a long chain of deductions. The crutch that mathematics provides to everyday reasoning becomes essential as sociology moves toward the analysis of complex systems and predictions based on extended chains of deductions" (Coleman, 1964, p. vii).

This dissertation does not aim at predicting social behavior. Howevwe, the abstract mathematical sociological deductions allow a general applicability of the results in various contexts, whenever the assumptions of the deductions hold true. Exemplarily, in this

dissertation the abstract deduction on path dependence induced behavior is applied to the climate-conflict nexus.

> "To examine behavior in all its complexity in any fashion but a purely descriptive one is far beyond our intellectual capacities. We must slowly analyze small parts at a time before we can hope to put the parts together again. […] It is in such a situation that the less rich but more precise language of mathematics becomes a useful - and sometimes very powerful - tool. It may be, then, that despite the ultimate complexity of the behavior which sociologists attempt to explain, a language as bare an unadorned as that of mathematics can prove useful. It is, in fact, the paradoxical combination of simplicity and a potential for expansion into complexity which constitutes much of the value of mathematics as a language for science" (Coleman, 1964, pp. 1-2).

Coleman presents an understanding of mathematical language based on numbers, variables, relations, and objects. This is interesting from the perspective that mathematics in its fundamentals uses a mathematical language that is structured by assumptions, definitions, theorems, hypotheses, and their abstract theoretical proofs and separate examples as applications. In using this formal structure, a mathematician aims at clarity, simplicity, and transferability because of its distinctly abstract causality that purely consists of mathematical logic and is therefore applicable in all contexts whenever the assumptions hold true. That way, sociological network theory benefits from mathematical graph theory, relational sociology from formal algebraic relation theory or combinatorics, or empirical sociology from mathematical statistics and stochastics. This applicability in other contexts due to its abstract set of logical deductions is a great strength of mathematics because it allows to just extend theorems once they are proven in other mathematical contexts or even in other disciplines such as natural sciences, social sciences, or humanities, covering even the wide span from finance to engineering. The pure mathematical logic allows the combination of theories whenever the notations can be combined, and even the expansion of theories into additional dimensions, onto different topologies, and to analyze embedded dynamics.

Therefore, in this dissertation when I use mathematical sociology I try to make the definitions and the assumptions as clear as possible, try to make as few assumptions as possible, try to

build on as little "external" theory as possible, not counting the one created here. And if external theory is taken into account, I try to use widely accepted theories, which then are likely to be true according to Habermas' definition of communicative truth via a consensus (section 1.2.2.2). I use a mathematical language of "theorem" and "proof" to structure the following mathematical sociological deductions. The mathematical sociological proofs that I reach, I end with "q.e.d.s.", which is supposed to relate to the usual "q.e.d." at the end of proofs in mathematics, which stands for the Latin "quod erat demonstrandum", which is "what had to be proven" in English. Similarly, "q.e.d.s." shall stand for "quod erat demonstrandum sociologice", which is in English "what had to be proven sociologically". The idea is to indicate that even though the logic in the complex conclusion chains is mathematically rigorous, still the conclusion is based on sociological theory, which is great for doing sociology but which is not mathematics.

To structure the theory development following a mathematical logic, which is applied to advance the sociological theory, three approaches can be defined, which can be found in the mathematical theory context.

1.3.3.1 First approach: atomistic approach

To use an atomistic approach in sociology would mean to define single elements such as people, and a minimum set of assumptions on what kind of features they may have like making decisions or acting. Then a relation can be defined as some kind of social interaction among a given pair of those persons and perhaps an order such as a linear hierarchy. And then conclusions can be drawn from these, adding more definitions with further expansion of the theory.

1.3.3.2 Second approach: dynamics

This second, more advanced, approach allows to start with considering dynamics instead of considering only individual people, from whom the dynamics would need to be aggregated at some point. Taking the perspective of dynamics can help to understand further dynamics

without the necessity to disaggregate them into all their details before re-aggregating them for their mere definition.

1.3.3.3 Third approach: unproven hypothesis

The third approach is especially interesting for sociologists because it allows to build on existing theories, no matter whether they are "proven" in a mathematical sense, or not. Of course, then the risk is embedded that all conclusions may tip once the hypothesis is proven to be right or wrong. If it is proven to be right, all mathematics built on it is also proven to be right and may be used forever. But once the hypothesis is proven to be wrong all mathematics built on it may either be right or wrong because from a wrong assumption you can conclude anything. It could happen though that it can be easily corrected, once the actual proof is out because sometimes only some cases need to be excluded or considered separately.

1.3.3.4 Preview on the mathematical sociology used in section 1.4.1

Using this understanding of mathematical sociology, I start out with the definition of the path-dependent process and the perspective of a dynamical process (second approach). Then assuming the existence of path dependence, its effect on an involved person's decision-making and actions, and the least-effort-principle in social psychology (third approach), I prove mathematically sociologically that path dependence triggers affected people to increasingly practice following behavior (Theorem 1, based on chapter 4). This conclusion is the reduction from the macro to the micro level (Figure 2).

Afterwards, I start out with ideal type path-dependent agents who are defined to practice a following behavior (first approach). For each single agent, the following behavior can be mapped in an egocentric directed path-dependent social network (PDSN) (chapter 5). Considering more than one agent and the related PDSN for each, the PDSNs can be connected if one agent follows another one, which makes the latter one part of the first one's PDSN. Opinion dynamics can cascade through such connected PDSNs, which can be used to explain path-dependent butterfly effects in combining informational and inter-systemic cascades (chapter 5). Based on the theory of PDSNs with an exception that is slightly based on the new

model framework (chapter 4), a theorem and a corollary are proven mathematically sociologically on path dependence, shaping the decision-making behavior in the PDSN into following only a shrinking number of others (swarming) or following a fixed set of others with a fixed importance (first to third approach). This conclusion leads from the micro and the macro to the meso level (Figure 2).

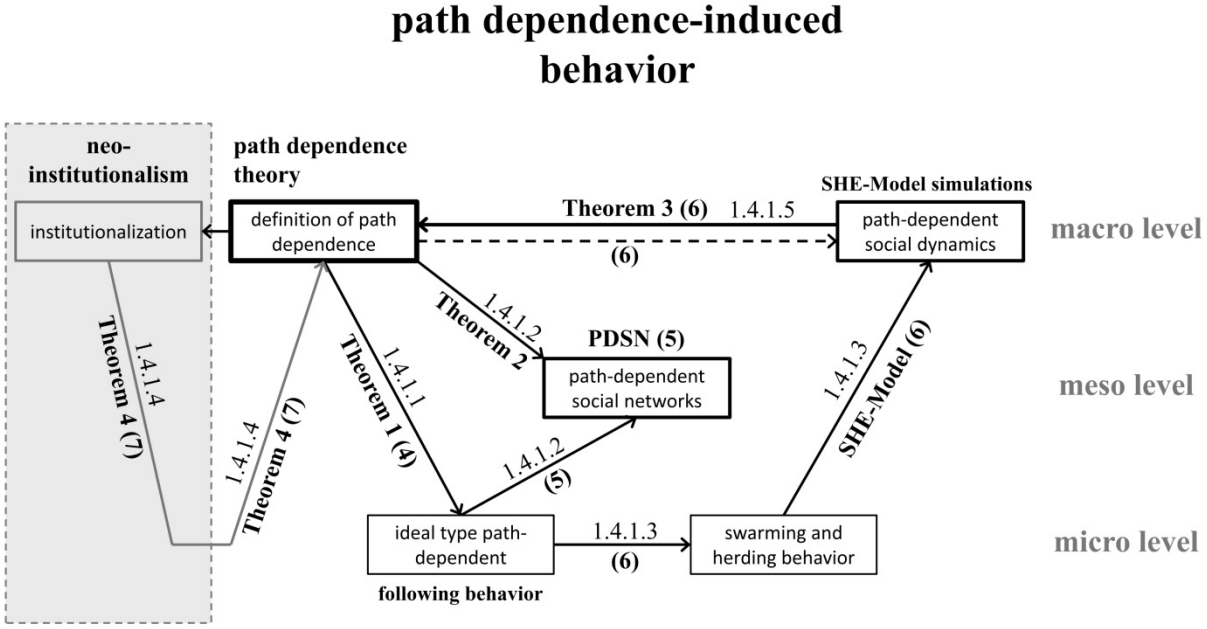

Figure 2 Complex causality for path dependence-induced behavior, which is proven mathematically sociologically in section 1.4, based on the chapters 4 through 7.
The chapter number, from which the respective method or argumentation is drawn, is noted in brackets, e.g. (5). The number of the section, in which the theorem is proven or the causality of the link is presented in this introduction, is also labeled at the linkage, e.g. 1.4.1.2.

After switching from social network theory to ABM, again, I start out with ideal type path-dependent agents who are defined as practicing following behavior (first approach). In the new model (chapter 6), a group of ideal type path-dependent agents is simulated as swarming and herding agents affected by an environment (*SHE-Model*). The simulation runs with the *SHE-Model* and the analyses of the results indicate that the theorem can be proven mathematically sociologically that the opinion-dynamics simulated with the *SHE-Model* are path-dependent (chapter 6). This conclusion leads back from the micro level to the macro level (Figure 2**Fehler! Verweisquelle konnte nicht gefunden werden.**).

Later on, the theorem is proven mathematically sociologically that each institutionalization is path-dependent (chapter 7) (third approach). The proof of the theorem is based on the definition of the path-dependent process, a process oriented neo-institutional definition of an institutionalization (Meyer & Rowan, 1977), the theory of primary and secondary socialization (Berger & Luckmann, 1979) and Giddens' duality of structure (Giddens, 1984).[3] This conclusion leads from institutionalism to path dependence theory, from the macro through the micro level back to the macro level (Figure 2, left side).

1.3.4 Methodological basis for the discussion of climate change-induced conflict

The discussion of climate change-induced conflict (chapters 1 through 3, sections 1.4.2, 1.4.3, 1.5) is based on a comparative review of the peer reviewed scientific literature on the linkages between climate-related indicators and data on violent conflict using large-n designs, published between 2004 and 2012:

> "To come to conclusions about the effect of climate change on violent conflict with validity beyond single cases, we limit the analysis to (quantitative) empirical studies using regression analysis based on conflict and climate data because of their increasing importance in the recent debate and the difficulties associated with the comparison of (qualitative) field-research studies. We analyze the results of recent relevant studies, classifying them with the help of a number of criteria such as specified climate-conflict link, conflict type, region, analyzed period (Table 2) and data used to carve out differences and similarities. We limit the analysis to studies published since 2004 and accept their academic credibility as articles published in peer-reviewed scientific journals" (chapter 3, section 3.2).

For further analysis an analytical framework is created of complex interactions between the climate system, the environmental system, human security and societal stability (two designs,

[3] The discussion and conclusion sections are not mathematically rigorous because stating all assumptions in these parts would exceed the scope of this introduction to the dissertation.

one in chapter 2, Figure 7, and one in chapter 3, Figure 8). In section 1.4.3, based on this analytical framework (Figure 7) and an extraction of potential intermediate factors from the literature review, a potential path-dependent feedback loop is visualized that reinforces conflict, which is driven by climate change and explains the potential effect of climate change as a threat multiplier in terms of path dependence. Also, it supports the impression of potential double exposure (Figure 10) if the related conflict theories are applicable (Figure 3).

1.4 Applications

What kind of social behavior can path dependence induce? Can path dependence induce consensus or conflict? Can climate change lead to conflict? In this section, the previously described methodologies (section 1.3), especially mathematical sociology, are applied to expand existing path dependence theory and to deduce an understanding of path dependence on the agent level as basis for the answering of the research questions. To answer the question whether path dependence induces consensus or conflict two perspectives are taken: First, the idealized modeling perspective, in which a group of ideal type path-dependent agents is analyzed, and in which only consensus is discovered. Second, the understanding of path dependence in real life is analyzed using the conflict theories presented in section 1.2.2.1, which reveals an ambivalent result: depending on the conflict theory used and whether or not there already is conflict present, path dependence reinforces the conflicting or non-conflicting behavior. However, there can as well be a "spillover" effect, by which path-dependent dynamics induce conflict on non-following persons. The question whether or not climate change leads to conflict is answered by analyzing extracts from a literature review and connecting them in a new way in a complex analytical framework to visualize a path-dependent feedback loop reinforcing conflict.

1.4.1 Path dependence-induced social behavior

How can an attribute of a social process such as path dependence induce a special kind of social behavior? In mathematics, deductions can be started with assumptions. So using mathematical sociology: Let's assume path dependence exists. Thus, there is a self-

reinforcing process with the tendency towards a lock-in. And let there be people involved or affected by that path dependence, accordingly, involved or affected by the self-reinforcing process, which has the tendency towards a lock-in. Then according to chapter 4, path dependence affects those people by influencing their behavior towards an ideal type path-dependent behavior, which is a following behavior. The tendency to practice following behavior implies that in their decision-making and actions they are more likely to follow others than before being affected by path dependence. These others can be for example other people, the masses, or norms. How path dependence exactly induces a following behavior is further elaborated in the next theorem and its associated proof, which is based on chapter 4.

1.4.1.1 Path dependence from the macro to the micro level

Theorem 1: Path dependence triggers affected people to increasingly practice following behavior.

Proof of Theorem 1 (based on chapter 4)

Let path dependence exist. Let there be a person P affected by path dependence. Then P performs a couple of similar actions connected to the self-reinforcing process, which has the tendency towards a lock-in. And P's action decisions are influenced by path dependence. How does path dependence evolve in affecting a person's action decision-making behavior?

Path-dependent behavior cannot be entirely explained by utility theory (Mahoney, 2000). Accordingly, there needs to be another component in the decision-making process that cannot be explained by mere rational choice theory. And path-dependent decisions are not substantially rational (Simon, 1976). Therefore, a new model frame is necessary to have as few assumptions as possible and particularly that does not assume a rational choice from the very beginning. This makes it possible to also describe the part of path-dependent decisions that differ from being substantially rational. Similar to Esser's model of frame selection (Esser, 2005), but using fewer assumptions than him, the new model frame (chapter 4) separates the decision-making process at different levels of consciousness that can be applied

to a person reaching an action decision.[4] Let's assume the model assumption that only when an automatic-spontaneous decision is deemed impossible or infeasible, other decision criteria are added to the decision-making process.

> "Whatever causes similar actions […], the way of acting like that becomes more and more a habit. It is possible to shorten a decision process by merely following a habit without thinking anymore (on levels 2 or 3), or evoking further (or any) decision criteria. Because of the least-effort principle (in social psychology; Moskowitz et al., 1999), this shortening of decision processes is what occurs if a path is followed for a longer period of time. Thus, the more path-dependent decisions an actor reaches, the more his process of decision-making is just a matter of following some routines or rules because already the process of having and applying habits or routines again becomes a habit (according to the least-effort principle; Moskowitz et al., 1999). Of course, this is a very detailed description of a self-reinforcing process, because in the described way a habit or routine gets reinforced" (chapter 4, section 4.3.3).

According to the citation (chapter 4), using the new model frame it can be concluded that the "couple of similar actions" by P lead to P's creation of a habit or routine. Thus, P tends to create a habit or routine out of these similar actions which are reinforced while being affected by a path-dependent process. But what happens when this person P who acts path-dependently in this beginning routine or habit is confronted with a previously unknown situation where that action seems to be no longer applicable? P either simply continues to follow the same routine (chapter 4). Or P does what P usually does (whatever that is) when being confronted with a new situation (which is like a routine on level 3 in the new model frame). Alternatively, P needs a new routine to match that particular new situation. But easier than creating a new routine oneself is the adaptation of routines, rules, or standards from other decision instances. And actually, P does not need to adapt an entire routine. He just needs an action draft for that one new situation. Therefore, P is more likely to just copy an action for that new situation.

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[4] The exact model description as well as its applications to Esser's ideal type automatic-spontaneous and ideal type rational-calculative to show the connectivity of the new model frame can be found in chapter 4. The application and conclusion on the ideal type path-dependent will be summarized there.

Therefore, being confronted with a new situation, P does one of the three alternatives:

(1) P continues to perform the old routine.
(2) P uses the routine on the meta level, which is to do what P always does when being confronted with a new situation.
(3) P adapts an action draft matching that particular new situation.

No matter which of these alternatives P chooses, that choice again gets reinforced over time as P is affected by path dependence.

This implies that if P chooses alternative (1) and just performs the old routine, a routine starts to evolve on the meta level to ignore new situations and just follow old routines (1).

If P chooses alternative (3), the copying of an action draft for matching a new situation is reinforced and on the meta level the routine starts to evolve to copy an action draft whenever being confronted with a new situation. And a new routine is initiated with that copied action so that if the situation stays that way, the new action draft can become a routine (due to the least-effort-principle).

If P chooses alternative (2), this meta-level routine still needs to result in some action draft selection (due to the new model frame). So this meta level could either be to always perform an old routine again (which then would indirectly be alternative (1) again), or to always adapt an action draft when being confronted with a new situation (which then would indirectly be alternative (3) again), or to do just one specific action like “keep smiling”, which might or might not match that new situation but again gets reinforced as a beginning new routine (like the action draft in alternative 3).

So now, thinking in dynamics, what happens when new situations occur to P over time again and again? Either P “keeps smiling” or P’s actions get reinforced into performing either old routines if P is totally locked-in, or copying action drafts. The match-up with a new situation is more likely to be better with a copied action compared to old routines or especially compared to the unique “keep smiling” action. Thus, the reinforcement is likely to be stronger for alternative (3), if tried out once by P.

But if P always adapts an action draft when being confronted with a new situation and if new situations occur very frequently to P, P creates the routine of adapting action drafts. And a routine of adapting action drafts is following behavior.

q.e.d.s.

Now that Theorem 1 that path dependence triggers affected people increasingly to perform a following behavior is proven mathematically sociologically, it can be used for further deductions. If there is more than one person affected by the considered path dependence, the affected people may interact. Their resulting social behavior is accordingly induced by path dependence, too. Thus, the question can be posed whether anything can be said about the subsequent induced social behavior. How does a group of people all affected by path dependence interact? What dynamics can result? To analyze these questions, an ideal type path-dependent is created, which is a stereotype of the following behavior induced by path dependence (chapter 4). Thus, now the question can be posed in a more abstract way: How does a group of ideal type path-dependent agents interact?

To address this research question using mathematical sociology, there are two approaches applied in this dissertation: A social network perspective (chapter 5) and agent-based modeling (chapter 6).

1.4.1.2 Path-dependent social networks (PDSN)

Based on the ideal type path-dependent agents' decision-making process, which is to follow others, egocentric directed networks can be created for each agent showing which other agents the considered ego one tends to follow (chapter 5). The so-called path-dependent social network (PDSN) intuitively maps the ego pointing to each other agent whom the ego follows. Using this methodology, the ego can be considered to follow more than one other agent at once, an arbitrary number of agents when averaging or weighting diverging opinions of the related others. And the approach allows for a changing set of agents whom ego follows, also possibly changing with the decision-making topics, as you would consider to consult other agents for computer questions than for fashion. In addition to including the effect of path dependence in the following behavior of each ego agent, path dependence may show up in

reinforcing formerly used directed links to other agents to increase their impact on ego's future decision-making and thus self-reinforce ego's dependence on those other agents. For example, theoretically you could have thousands of computer experts but over time you are likely to rather rely on one or two. For each other agent whom the ego agent follows, their PDSN can be considered, too. These PDSNs are all different because the agent considered as ego is different. But the PDSNs may overlap, for example, if friends rely on each other or if a group of agents shares the same computer expert. In this interconnected set of PDSNs, opinion dynamics can cascade through the directed links among egos as considered in chapter 5. In the example of the Fukushima earthquake and connected political shifts in Germany to shut down nuclear power plants, the changes in local behavior triggered by regionally distinct events can be explained as a cascade through the PDSNs and thus as induced by path dependence (chapter 5).

> "The cascading potential of natural disasters is vividly demonstrated by the March 11, 2011 earthquake in Japan which triggered a chain of events. These include a tsunami wave traveling across the Pacific and a nuclear reactor accident spreading radioactivity into the atmosphere, forcing people to evacuate from the region, not to speak of potential implications for the power grid, stock markets, the oil price and the economy in general. The shock waves of the disaster even affected German politics by triggering the election of a Green Party Prime Minister in one of most conservative federal states. This indicates how many factors may combine in such a disaster with implications across continents. How can these cascading effects be explained?" (chapter 5, section 5.1).

Starting out with social network theory with a focus on network diffusion and threshold models, two types of cascades are presented: informational cascades and inter-systemic cascades. Informational cascades explain the following behavior of individuals. Inter-systemic cascades describe spillover effects from one system to another one. "While the first one is more applicable to analyze the behavior of demonstrators, the latter one is more adequate to describe the effects that are triggered by a natural disaster" (section 5.1). To combine both approaches, path dependence theory is introduced including PDSNs. Exemplarily, the theory of PDSNs is applied as a framework to several recent cascades including the North African

protest movements, and the aftermaths of the Japanese earthquake. Using path dependence theory and applying the PDSNs, the following behavior of individuals can explain spillover effects of natural disasters on natural and social systems inducing social behavior. Afterwards, the PDSN framework is used to analyze potential future risk cascades of climate change:

> "In a multi-agent setting, actors mutually adapt their targets, values, and actions to those of other players to change the outcome to their own favor. But besides deliberately changing the behavior of oneself or others, structural effects such as those of the individual PDSN influence each agent's action. Thus, the collective outcome cannot be directly composed of individual targets and values but is a result of the social dynamics. Therefore, it is necessary to consider the steps in each agent's individual PDSN and the evolving dynamics" (section 5.4.3).

Theorem 2: In a PDSN, path dependence shapes the decision-making behavior either in following a shrinking number of others or in following them with equal importance. One exception: If a specific decision-making behavior including all others is close to lock-in on the meta level of the ego's decision-making framework, then path dependence rather reinforces that behavior instead of changing it by changing the importance of included others.

Proof of Theorem 2 (based on chapters 4 and 5):

Let there be an ego with his or her related PDSN, both affected by path dependence. Then linkages to others, used once for decision-making are increasingly likely to be used again because they are reinforced by path dependence. Making used linkages more likely to be used again reduces the likelihood of other previously unused linkages to be included in the decision-making the next time (compare urn model of self-reinforcing processes, Arthur, 1994). Thus, the relevance of the other previously unused linkages for the ego's decision-making process diminishes over time.

Thus, either all linkages are used with equal importance at the very beginning, then there are no other previously unused linkages, or the previously unused linkages shrink in importance and with them the number of those who are followed by ego. If at some point ego follows the remaining others with equal importance, this behavior locks in.

Exception:
Thinking in terms of the previous model framework (chapter 4), it is possible that at the very beginning of the considerations ego has a specific decision-making rule including the PDSN with a predefined importance of the others. Then it is possible to just follow the same decision-making rule including the following of others with potentially unequal importance. This can be the case if this specific decision-making rule following all others but with a fixed importance is already embedded on the meta level. Then instead of shrinking the number of followed others and thus changing the decision-making rule, rather the concrete decision-making rule itself gets reinforced on the meta level of ego's decision-making framework.

q.e.d.s.

Corollary 1: Path dependence either locks in a fixed decision-making rule on the meta level of an ego's decision-making framework or transforms ego's decision-making into a simple swarming or herding behavior.

Proof of Corollary 1 (based on Theorem 2 and chapter 5):

Let there be an ego with the related PDSN both affected by path dependence. Let's assume that there is no fixed decision-making rule related to the ego's PDSN on the meta level of ego's decision-making framework. Then due to the Theorem, path dependence reduces the number of used others over time until the remaining ones are followed with equal importance. Thus, there is either only one other agent left whom ego follows like following a personal expert, which is a simple form of swarming behavior. Or there is more than one other agent left whom ego follows with a fixed (e.g. equal) importance (like averaging their opinions or following the majority).

If there is a fixed decision-making rule related to the ego's PDSN on the meta level of ego's decision-making framework, this gets reinforced as shown in the Proof of the Theorem.

q.e.d.s.

1.4.1.3 The *SHE-Model*

To simulate ideal type path-dependent agents, I have created an ABM, the *SHE-Model*, which stands for "Swarming and Herding agents affected by an Environment" (chapter 6). Ideal type path-dependent agents are set up as either swarming or herding agents. While swarming agents follow their neighbors within a constant vision, herding agents follow the masses of the entire group. To learn about the potentially evolving dynamics within such a group of ideal type path-dependent agents, this group is affected by an environmental feedback that influences the opinion dynamics of the agents in the simulation. During the model runs it is possible to monitor how long it takes for the group of ideal type path-dependent agents to adapt to a set environmental feedback; who adapts when? - the swarming agents versus the herding agents; and if a lock-in is reached: how many agents have been able to adapt before being locked in?

Compared to the application of PDSNs, the *SHE-Model* is based on very simple decision-making rules: For the opinion dynamics, a swarming agent points to one agent within his vision and copies that agent's opinion. A herding agent copies the majority opinion of the entire group. But in the PDSNs it can be analyzed that path dependence shapes decision-making behavior by reducing the number of others whom an ego tends to follow, or locks the ego into following the majority of all others. Thus, path dependence shapes the ego's decision-making behavior towards either a swarming or a herding behavior as simulated in the *SHE-Model*. But in the PDSNs, path dependence also shapes the decision-making behavior by increasing the likelihood to follow the same agents as before. In the *SHE-Model*, this increasing likelihood for swarming agents to follow the same agent again is set up in the swarming movement: swarming agents tend to group with others in a swarm formation, which includes that agents close to each other are more likely to stay close to each other. Thus, if the vision is small enough the swarming agent tends to follow the same agents again and again

because those are the only others within reach. In the *SHE-Model* simulations, herding agents move all in the same direction, which is the average heading of all agents of the group.

Theorem 3: Simulated with the *SHE-Model*, in a group of ideal type path-dependent agents the opinion-dynamics are path-dependent.

Proof of Theorem 3 (based on chapter 6):

In the *SHE-Model*, when simulating two dynamics – opinion dynamics and movement dynamics – both dynamics can reach a lock-in (the opinions are simulated via the colors of the agents):

> "In the situation of the opinion-lock-in either all agents have the same color or there are agents who cannot reach out to adapt to the environment anymore. Therefore, there are a number of agents of one color left that cannot change anymore (cf. e.g. Figure 21). In the situation of a collective-movement-lock-in all agents have the same heading so they move collectively in the same direction and their positions relative to each other do not change anymore. If a collective-movement-lock-in occurs there could also be an opinion-lock-in in the cases, when the number of agents of one color does not change anymore. But a collective-movement-lock-in can also happen without an opinion-lock-in if the number of agents of one color changes periodically within a frequently changing environment" (chapter 6, section 6.4.2).

In a stable environment and without movement an opinion lock-in is always reached and this happens fairly quickly. Depending on the spatial structure, the vision of the swarming agents and the size and respective density of the group of ideal type path-dependent agents, the number of agents who are able to adapt to the environment before the lock-in is reached varies a lot. Interestingly, herding agents are sometimes helpful to reach spatially remote parts of the group as soon as the herding agents adapt to the environment. But this can only happen if less than 50% agents of the entire group are herding agents because otherwise they would

just follow themselves as they would already constitute the majority of the group of ideal type path-dependent agents. Switching on the movement button allows collective-movement-lock-ins to occur but as long as the environment is kept stable the opinion-lock-in is usually reached more quickly. It takes longest to reach the opinion lock-in for a group with less than but nearly 50% herding agents and a small vision for the swarming agents. Only in a changing environment it sometimes takes very long to reach a lock-in, even about a thousand times longer for some constellations including a high percentage of swarming agents compared to a fixed environment. But in the simulation experiments with the *SHE-Model* (chapter 6), a lock-in is always reached, either an opinion-lock-in, a collective-movement-lock-in, or both at the same time (otherwise the run stops whenever the first lock-in is reached).

In the *SHE-Model*, the simulated opinion dynamics are self-reinforcing, which is very important because together with the observed tendency towards a lock-in the self-reinforcement implies path dependence (the opinions are again simulated via the colors of the agents):

> "If there are more than 50% herding agents in the population, the masses consisting of the herding agents reinforces the predominant color. If there are less than 50% herding agents in the population, the environment enforces the correct color. Swarming agents spread the correct color within their reach and thus reinforce the color via the hierarchical structure of the bottom-up network. The spatial hierarchical structure has the effect that the larger the group of agents of the correct color is, the higher the probability becomes for the rest of the agents to adapt to that color. The lock-in can occur before all agents are reached as described above. But nevertheless, before the lock-in the opinion dynamics are self-reinforcing" (chapter 6, section 6.4.3.2).

q.e.d.s.

1.4.1.4 Linking institutionalism and path dependence theory

Theorem 4: Based on a neo-institutional understanding of institutions, Giddens' duality of structure, and Berger and Luckmann's theory of primary and secondary socialization: Each institutionalization is path-dependent.

Proof of Theorem 4 (based on chapter 7):

Let a *path-dependent* process be a self-reinforcing process with the tendency for a lock-in. Let *internalization* be the process of creating an own subjective understanding like an internal picture of the objective event[5]. Let *significant others* be actors who act in comparable situations in the same manner so that an actor can understand the signification of it. Let *the generalized other* be the abstraction from the roles and attitudes of concrete significant others.

Then *primary socialization* starts with internalization and creates a progressive abstraction from the roles and attitude of specific others to roles and attitudes in general in the actor's consciousness (Berger & Luckmann, 1979, p. 152f.). "When this concept of the generalized other has been established in the consciousness of the individual primary socialization ends" (section 7.3.1.2.3).

Let *secondary socialization* be "the internalization of institutional or institution-based 'sub-worlds'" (following Berger & Luckmann, 1979, p. 158; emphasis by Berger and Luckmann).

Let the *duality of structure* exist, which means that structure is means and end of action (Giddens, 1984).

Let each institution be the result of an institutionalization. Let at least one actor be involved in each institutionalization "who supports the process of institutionalization, which means that the foundation of the future institution must already exist in his subjective reality" (section 7.1). Then this actor gradually builds up social structure. Due to the duality of structure, the built up social structure that begins to exist has an influence back on the actor. Thus, in the

[5] Referring to "The beginning point of this process is internalization: the immediate apprehension or interpretation of an objective event as expressing meaning, that is, as a manifestation of another's subjective processes which thereby becomes subjectively meaningful to myself" (Berger & Luckmann, 1979, p. 149).

considered process of institutionalization the beginning existence of the institution is the result of the actor's behavior. But as a medium, the institution that begins to exist also affects the actor's subsequent decisions and actions and thus again influences the process of institutionalization. More concretely, the institution influences the actor in a process of socialization.

> "Because the actor is the one who created the surrounding, this process [secondary socialization] bears a resemblance to primary socialization. The institution, which starts to exist, perfectly fits the actor's subjective reality. Thus, this new social structure gives feedback of congruence to the actor. The longer this institution exists and the stronger it gets, the more the actor's significant others, which have been relevant for this institution, re-influence the actor in congruence with the actor's inner self. This means that by following the process of institutionalization, the creating actor is increasingly affirmed in his action of creating the institution.
>
> Furthermore, the intensity of socialization, in which the new institution affects the considered actor, increasingly corresponds to the intensity of primary socialization because the significant others increasingly match the actor's subjective reality" (chapter 7, section 7.4.1.2).
>
> "From the detailed consideration of socialization processes within the process of institutionalization it can be concluded that the actor's decisions are increasingly aligned with the process of institutionalization and 'with the institution'. Therefore, the institution's function as a medium strengthens the process of institutionalization, which then again results in a more intense institution, once again serving as result and medium and so on. This way, a feedback loop is integrated within the process of institutionalization, which has the effect that the resulting institution starts to get self-reinforced the very minute it begins to exist." (chapter 7, section 7.4.2)

Consequently, the institutionalization is a self-reinforcing process with the tendency towards a lock-in, which is the institution. Therefore, the institutionalization is path-dependent.

q.e.d.s.

1.4.1.5 Results on path dependence-induced social behavior

In the proof of the first theorem (Theorem 1) it is shown that path dependence triggers affected people to increasingly practice following behavior (based on chapter 4). Thus, path dependence induces a following behavior of affected persons. What else does path dependence induce? Looking at the issue from a social network perspective, it can be shown that transdisciplinary and trans-regional cascades can be explained like an overarching butterfly effect through PDSNs (chapter 5). Path dependence furthermore induces affected ideal type path-dependent agents to either follow a diminishing number of agents in a swarming manner, or follow the same set of agents in the same way again and again in a herding manner with the tendency towards a lock-in (Theorem 2 and Corollary 1 based on chapter 5). And also from an ABM perspective using the *SHE-Model*, the analyzed group of ideal type path-dependent agents practices path-dependent dynamics, too (Theorem 3 based on chapter 6).

Corollary 2: Path dependence self-reinforces path dependence

Proof of Corollary 2:

Path dependence induces path-dependent processes (compare Theorem 2 and Theorem 3). Thus, via the induced following behavior path dependence reinforces path dependence. Therefore, path dependence over time self-reinforces path dependence with further increasing effects on involved people who are affected by path dependence from more than one path-dependent process simultaneously and with increasing number and intensity.

q.e.d.s.

Interestingly, in real life every social person is affected by path dependence at least with respect to some actions or with regard to some topics because every institutionalization (in the neo-institutional definition, which includes routines and habits) is path-dependent (Theorem 4). Accordingly, every social person is at least in those actions or respectively for those topics triggered to perform a following behavior, if the theoretical mathematical sociological assumptions from Theorem 1 hold true. This implies for those cases that every social person is triggered to act like an ideal type path-dependent. If the social persons allow for the influence by path dependence in the considered action decisions, social dynamics may occur like the ones described from a social network perspective and summarized in Theorem 2 and Corollary 1 (chapter 5), as well as those described from an agent-based modeling perspective analyzed in chapter 6. If the involved social persons allow for the induction by path dependence and practice the resulting path-dependent social dynamics (Theorem 3), they further increase the overall effect of path dependence on all involved agents (Corollary 2). But increasing the overall effect of path dependence reinforces the likelihood of path dependence induced behavior in the next action decisions if one assumes that people are the more likely to allow the influence of path dependence the more intensely they are affected by it[6].

1.4.1.6 Can path dependence induce conflict? - ideal type path-dependent agents

So far, this section has analyzed path dependence induced social behavior in a very theoretical way, considering ideal type path-dependent agents in groups of ideal type path-dependent agents, who all only practice following behavior. Staying in this theoretical context, a definition of conflict among ideal type path-dependent agents appears necessary. On the other hand an absence of conflict, a consensus, could be analyzed. Considering Habermas' consensus theory of truth (section 1.2.2.2), (Braaten, 1991, p. 23), the central process deciding whether a truth claim for a statement is proven is the discursive argumentation. Thinking of a group of ideal type path-dependent agents who may have reached conformity, any argumentation would be non-discursive or rather reach the second mentioned basic

[6] I say if the social persons "allow the influence by path dependence" because different from a theoretical ideal type path-dependent agent a real life social person has the choice to allow the influence by path dependence or to deliberately act differently. But if the social persons start to allow path-dependent behavior to occur they are also prone to reach the state of the lock-in, in which the social persons may feel as if they would not have the choice to act differently anymore.

"modality": "the proof that a claim is necessarily true (the impossibility of the negation of the claim)". And when there is consensus, there is no conflict. This implies that if, for example, in simulations with the *SHE-Model* a lock-in in conformity is reached, no conflict would be present.

Thinking a little further, one could ask if the change in opinion, as simulated in the opinion dynamics, could imply the presence of conflict. But among ideal type path-dependent agents even a change in an opinion is the result of the following behavior of the ego agent, not a result of coercion by the followed agent. Thus, the ego agent is not forced into this new opinion (top-down) but rather has changed it because the agent he followed has changed his opinion, or because he has followed a different agent who has the different opinion (bottom-up). Again, the Habermas' consensus theory can be applied because if there is a procedural impossibility of the negation of the claim, this serves as proof that the claim is necessarily true. Accordingly, within the *SHE-Model* there is no conflict embedded in the simulations.

Considering the PDSNs, the same argument holds as there are also only ideal type path-dependent agents included who practice bottom-up following behavior, not a top-down enforcement. In the *SHE-Model* the decision-making is defined by the location and a random selection among the neighbors to have one agent to which the ego agent points to for copying his opinion when ego is a swarming agent. Or the ego agent follows the average of all agents, the masses, if ego is set up as a herding agent. However, in using the theory of the PDSNs the final decision-making rule is not necessarily predefined. So theoretically, the agent can feel an inner conflict in deciding for some decision-making rule. If path dependence reinforces the PDSNs over time, the linkages to others whom the respective ego agent follows more seldom may fade out over time (due to the Theorem on PDSNs). PDSNs may get reinforced into following an average of the consulted others because they are equally weighted and equally reinforced by path dependence, or shape into a more simple following-only-a-few-agents rule or even a following-only-one-agent rule because those few or that one are the most frequently used contacts (due to the Corollary on PDSNs). Hence, the decision-making may become more simple or nearly preset and that way path dependence may reduce potential inner conflict over time.

1.4.1.7 Every person is likely to act like an ideal type path-dependent for some actions

The question remains to what extent real people act like path-dependent agents? What can be learned from the dynamics and simulations of a group of ideal type path-dependent agents for potential conflicting situations? And what effect could path-dependent behavior induce in a group, in which not everybody is acting as an ideal type path-dependent agent? The theory on the deduction of the ideal type path-dependent states that the more a person is affected by path dependence, the more that person is likely to act like an ideal type path-dependent agent (chapter 4). The basic assumption of this section of path dependence induced social behavior is the existence of path dependence at all. There are empirical studies revealing path dependence in studied cases (section 1.2). Of course, the case studies prove the existence of path dependence. And combined with the self-reinforcing dynamics of path dependence, people affected by path dependence in those cases are to some extent likely to act like ideal type path-dependent agents. But theoretically those cases could be socially distinct cases and would make it unlikely for an arbitrary person to act like an ideal type path-dependent agent. Therefore, the proof of the theorem that each institutionalization is path-dependent (Theorem 4 based on chapter 7) is very important.

The definition of an institution used in chapter 7 is the neo-institutional definition which includes all norms, routines, and habits in the definition as institutions (Meyer & Rowan, 1977). This implies that every norm, every routine, and every habit throughout society is path-dependent. Thus, every time a person is affected by a norm, a routine, or a habit, that person is affected by path dependence, which is the case for everybody, regularly, very often, daily: “The routine (whatever is done habitually) is a basic element of day-to-day social activity. […] The term ‘day-to-day’ encapsulates exactly the routinized character which social life has as it stretches across time-space” (Giddens, 1984, p. xxiii).

Consequently, to that extent – every person, regularly, and very often – people are likely to act like an ideal type path-dependent agent. This does not imply the necessity of any of them to act like an ideal type path-dependent agent. But the mathematical social deduction proves the likelihood and founds the basis for a certain probability of any person to act like an ideal type path-dependent agent, knowing that every person could theoretically act deliberately differently in real life. Thus, also the interplay of ideal type path-dependent agents has a

certain likelihood or even probability to show up in real life social behavior, induced by path dependence.

1.4.1.8 Can path dependence induce conflict? An application of conflict theories

The previous section has shown that within a group of ideal type path-dependent agents who all practice following behavior rather a consensus, and thus no conflict, prevails or is approached in a bottom-up non-coercive manner. Interestingly, an assessment of the obtained results from path dependence theory with conflict theories shows that path dependence can induce conflict: when people who allow the influence of path dependence interact with people who do not allow the influence of path dependence on the specific occasion. This resembles the enforcement of new norms on others who have not been involved before (secondary socialization; Berger & Luckmann, 1979; Coser, 1956). Furthermore, path dependence can reinforce existing conflicting behavior. On this basis, the developed innovation in path dependence theory can be analyzed in combination with previously presented conflict theories (section 1.2.2.1).

1.4.1.8.1 Man in nature

One situation described through the biological determinism is the fight of all against all in the absence of social order (Hobbes). Two different perspectives can be analyzed. On the one hand path dependence theory can be applied on a fighting person, on the other hand path dependence theory can be used to analyze following behavior and its impacts. Considering the fighting person, having shown path-dependent behavior can imply that the fighter just continues to fight even if the initial reason for fighting is no longer present. Without path dependence, the person might have stopped fighting once the reason is passed. So in this scenario, path dependence would induce increasing conflict. Thinking in terms of following behavior, people can follow others where they go, whom they fight etc.. One result can be that the ones following someone else gain power: if they fight the same one together, the underdog is likely to lose the fight while the group has higher chances to win. If there are more groups forming through following behavior, these groups may fight “all against all”. Then the larger group is more likely to win, which reinforces the following behavior. So potential fighters can just as well follow the larger group to save their own resources and assure their own winning.

But it may also occur that only the leaders fight and all others follow the winner afterwards. Then overall path dependence would rather have reduced conflict by reinforcing following behavior, which triggers hierarchies as basic social structures.

1.4.1.8.2 Aggression theory

Considering a potentially aggressive person, path dependence can occur on various levels (Berkowitz, 1993). On the level of sensitivity to regard or disregard potentially frustrating events; on the level of emotions that are triggered by the events; on the level of inner evaluation, whether to react in fight or anger; or on the sensibility to recognize present weapons or conflicts. On each of these levels path dependence can increase the risk of conflict or decrease the risk of conflict depending on whether the more conflicting or less conflicting alternative gets reinforced. E.g., if the person tends to disregard potentially frustrating events and path dependence reinforces this behavior, then it is unlikely that the person ever reacts aggressively after a frustrating event because it would hardly recognize it as such. If on the other hand the potentially aggressive person gets more and more sensitive to potential frustrating events the more such events occur, the likelihood increases for that person to react aggressively.

1.4.1.8.3 Action theory – rational choice theory

"Conflicts lead to adjustment or recreation of social norms and rules, new social structures are built and within the onset of conflict involved persons become aware of the rules." (cited from section 1.2.2.1.2 in this dissertation, referring to Lewis A. Coser)

Within the process of institutionalization, the newly-built structure, the institution, feeds back on involved agents, but also on not primarily involved agents. In this situation of secondary socialization, Coser describes that secondary socialization does not happen without conflict. However, it is in the situation of conflict that affected people become aware and learn to adjust to the new institution and its rules. Thus, in this definition, path dependence induces conflict.

1.4.1.8.4 Rational choice theory as conflict theory

The rational choice theory has been described in the section 1.2.2.1.3 based on the RREEMM model. Resourceful, restricted, expecting, evaluating, maximizing men (Lindenberg, 1985, p. 100f.) pairwise play prisoner's dilemmas and compute their individual SEUs (Coleman, 1990). Shaped by path dependence, RREEMM actors would reduce the time they spend with evaluating and choosing over time by just practicing the same alternatives again and again or by following their neighbors in what they do. Applying this to a prisoner's dilemma, a less optimizing and just repeating behavior could stabilize behavior on each of the four possible outcomes (both cooperate, only one cooperates and one defects, and both defect). Assuming that the RREEMM actors are not locked-in but still locally optimizing their behavior, they are still likely to end up both defecting. Interestingly, when including following behavior, both could consider that the other one follows his own behavior as well, so a cooperative behavior would be a more sophisticated outcome than both defecting, and both actors might reach cooperation as soon as one of them starts cooperating. As well they could reach back conflict as soon as one of them starts defecting again. Thus, depending on their timely foresight or timely local restriction in thinking, path-dependent actors in a prisoner's dilemma could reach all states with a larger likelihood for the both cooperating or both conflicting outcomes. Nonetheless also periodic switches are possible.

1.4.2 Climate change-induced conflict

Does climate change induce conflict? This question is not new. The literature review on this question yields ambivalent answers. Thus, further details are extracted as to what combination of climate change versus conflict is analyzed and what ways of induction they discover. Most of the reviewed studies seem to analyze the potential effect of precipitation changes and scarcity on resource conflicts. The new analytical framework visualizes the complexity of potential effects among natural and social systems, showing interactions, sensitivities, and vulnerabilities. There are two general definitions of climate change: one also includes natural changes and the other only considers those changes that can be attributed to human activity. In this dissertation I utilize the first definition, which is the one by the IPCC, in which climate change is induced by human behavior as well as by natural environmental systems:

> "Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods" (Parry et al., 2007, p. 6).

If I only refer to the human-made component of climate change, I refer to "anthropogenic climate change".

There is not one exclusive definition of conflict used in the context of the climate-conflict nexus. Every researcher may use a different definition of conflict, relating to the context of analysis and the included background theory. However, the literature review reveals that many studies share a common understanding of a resource-oriented agency theory as basis for conflict theory, which indicates the tendency towards a rational choice theory on resource conflicts (as presented in section 1.4.1.8.4). Quantitative studies usually use the definition given by the organization that collects and releases the conflict data. The definitions vary on what counts as a conflict, such as e.g. on state or government involvement, whether the conflict is only in one state or trans-regional, and the number of battle deaths (for example, Peace Research Institute Oslo, PRIO, only counts a conflict if it produces at least 25 reported battle deaths per year).

1.4.2.1 Data assessment

"While long-term historical studies suggest a coincidence between climate variability and armed conflict, empirical findings are less conclusive for recent periods. Understanding the different views provides a foundation for the prediction of future impacts on violent conflict" (chapter 3, section 3.1).

The statistical coincidence of climate variability and armed conflicts in long-term historical studies does not necessarily imply the induction of violent conflict by climate change (Kuper & Kröpelin, 2006). While statistical methods can show correlations, they alone cannot reveal the mechanism or the direction of causality if any link exists. Some researchers identify climate change, which is usually understood as related to a global warming, as a major driver of large-scale human crises in the Northern Hemisphere for a set of variables in the time period 1500-1800 (Zhang et al., 2011). However, other scientists (Tol & Wagner, 2010) conclude that cooler phases were more likely to be related to periods of violence than warmer ones in preindustrial Europe, comparable to findings for eastern China (Zhang et al., 2007). Accordingly, on the one hand researchers relate global warming to violent conflict, on the other hand, researchers relate global cooling to violent conflict. Thus, is it rather a matter of climate volatility and the change itself that induces conflict regardless whether it is cooling or warming? Or do interdependencies with other variables or dynamics prevent conflict in some cases or increase the likelihood of violent conflict in other cases?

A summary of the results of key peer reviewed quantitative studies published between 2004 and 2012 on the link between climate change and violent conflict is shown in Table 2. Of the 27 publications analyzed in Table 2, 16 publications find a link between climate change and violent conflict, while six publications state there has no link been found, and five publications show ambivalent results on the climate-conflict nexus. 25 of the listed studies have analyzed conflict in which at least one state is involved, five out of those have still included conflicts in which no state is involved and only two publications have only analyzed conflicts, in which no state has been involved. The latter two find a linkage between an increase in rainfall and an increase in conflict in East Africa for time periods ranging from 1950 until 2010.

> "As shown in Table 2, quantitative empirical studies are suited to identify significant correlations between climate variables and violent conflict, but they have limited explanatory power with respect to characterizing the causal pathways and their dynamics. In other words, empirical studies may find a correlation but they are hardly able to explain why. Furthermore, quantitative studies predominantly rely on state-based data captured in the UCDP/PRIO Armed Conflict Dataset (Table 2). However, PRIO's definition of conflict

limits the studies to conflicts with governmental involvement and an intensity of at least 25 battle deaths per year (Themnér, 2011). Hence low-level events such as protests, riots and inter-group violence are disregarded in such datasets. As climatic changes are expected to mostly affect local (non-government) conflicts, this is in general a significant shortcoming of quantitative studies. Recent projects like the Armed Conflict Location and Events Dataset (ACLED), the Social, Political and Economic Event Database (SPEED) and the Social Conflict in Africa Database (SCAD) attempt to fill the gap by including non-state conflicts, low-level violence, social instability events, and geo-referenced spatio-temporal patterns (see Busby et al., 2012; Nardulli & Leetaru, 2012; Raleigh & Kniveton, 2012; and the supplement in Scheffran et al., 2012b). Due to the huge amount of data it will take time until the upcoming databases cover longer periods and major parts of the world" (section 3.3).

1.4.2.2 Analytical framework (summarized from chapter 2 and chapter 3)

Leaving the data needs, the analytical framework focuses on the complexities in the climate-conflict nexus. In the new analytical framework there are shown linkages between four interconnected fields (Figure 7):

- **climate system**:
  temperature, precipitation, extreme weather, ice cover, ocean currents, and sea level;
- **natural resources**:
  water, land, ecosystems, biodiversity, marine resources, and non-renewables;
- **human security**:
  water, food, energy, health, income, and livelihood; and
- **societal stability**:
  political events, migration, violence, conflict, cooperation, and institutions.

"Adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the

> character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system" (Parry et al., 2007, p. 6).

In a social system, the conflict sensitivity theoretically describes the likelihood to react conflictively when being affected. In the climate system, climate sensitivity describes the likelihood for the climate to change when being affected like e.g. by a large amount of carbon emissions. Both these sensitivities are difficult to quantify given the complexity of the social system and the climate system. To gain further insights about potential mechanisms that may indirectly influence the climate-conflict nexus, vulnerabilities are discussed such as the environmental vulnerability when natural resources are exposed to climate change or the human vulnerability when people are exposed to climate change effects such as droughts, heavy rainfall events, or sea level rise and flooding.

> "Since the 1990s, there has been an extensive scientific debate on how the scarcity of natural resources affects violence and armed conflict (Bächler, 1999; Homer-Dixon, 1994). More recently, conflict studies pay attention to the vulnerability of natural and social systems to climate impacts (Scheffran & Battaglini, 2011). Vulnerability can be broken down into three factors: (i) exposure to climate change, (ii) sensitivity to climate change, and (iii) adaptive capacity (Parry et al., 2007). The last two can be affected by conflict. Many of world's poorest people are exposed to various risks to life, health, and well-being. If climate change adds to these risks, it can increase humanitarian crises and aggravate existing conflicts without directly causing them. The question is whether human development, resilience, and adaptive capacity can compensate for increasing exposure and sensitivity to climate change" (chapter 2).

While the exposure to climate change can be considered to increase with increasing climate change, the sensitivity to further climate change may rise with increasing climate change and the adaptive capacity may rather shrink with increasing climate change. Interestingly, conflict is not only a potential outcome of climate change affecting people but also feeds back on the sensitivity to climate change and the adaptive capacity by overall increasing the vulnerability

because conflict reduces resources that might otherwise have been used for mitigation, resilience or adaptation (Brzoska, 2012).

1.4.2.3 Induction mechanisms

What are the possible ways of how climate change potentially induces conflict? To consider the induction of conflict, of course, the definition of conflict matters. In the literature on climate change and conflict the "definitions of conflict vary with respect to the number of actors, casualties, and the degree of violence. In the context of climate change most studies refer to armed conflict, in which actors use force to achieve their aims" (chapter 3, section 3.3). This is an action-centered approach to conflict (action theory), which is coined by aggression (aggression theory) for achieving aims (rational choice theory) (cf. section 1.2.2.1).

> "Since the 1990s, there has been an extensive scientific debate on how the scarcity of natural resources such as minerals, water, energy, fish, and land affects violence and armed conflict (Bächler, 1999; Homer-Dixon, 1994). While many case studies suggest that environmental degradation and resource scarcity undermine human well-being, the effect on violent conflict "appears to be contingent on a set of intervening economic and political factors that determine adaptation capacity" (Bernauer et al., 2012, p. 1). Particular attention has been placed on the following intermediate factors (Scheffran & Battaglini, 2011; WBGU, 2008)" (chapter 3, section 3.4).

These central intermediate factors are: precipitation changes and variability, freshwater resources and scarcity, land and food, weather extremes, and environmental migration.

Climate change may lead to conflict via: resource conflicts; strong deviations from average precipitation; effects on economic growth; food insecurity, rising food prices; increased land invasions in regions with highly unequal land distribution; and crises after weather-related extreme events. But in some situations of crisis cooperation increases instead of conflict. Such

is the case in international water agreements on freshwater resources, after extreme events, or via remittances of environmental migrants. A global check for vulnerabilities reveals an additional insight on the double exposure to climate change and conflict even if climate change does not directly cause the conflict:

> "A comparison of the number of deaths from natural disasters and battle-related deaths in the past (scaled for comparability using the population in each country) reveals that both are highest in countries with a low human development index (see Figure 10). Many of these countries are home to the world's poorest people who already experience increased threats to their lives and health that undermine human development. If climate change adds to these risks and vulnerabilities, it can increase humanitarian crises and aggravate existing conflicts without directly causing them" (chapter 3, section 3.5).

1.4.2.4 Results of the literature review: does climate change induce conflict?

Even though the quantitative peer reviewed literature has been ambiguous, there have been indications for a linkage between climate change and conflict. And if climate change can induce conflict, this link may be even more relevant with potentially substantially increasing climate change in the future.

> "However, while quantitative studies tend to provide evidence for a link between climate change and violent conflict over longer historical periods, results for recent periods are more ambiguous. Other trends and events may have had a larger influence on violent conflict than climate change. Two examples from the recent past are the end of the Cold War and the increase in international activity to stop armed conflict in many parts of the world. However, without strong mitigation efforts future climate change may by far exceed levels that have been reached in human history. If major 'tipping points' of societal stability are reached, climate change may become a major driver of armed conflict in the future" (chapter 3, section 3.7).

Thus, it is worthwhile to analyze the complex analytical framework presented in chapter 2 (Figure 7).

> "A relevant constraint is the lack of understanding of the escalation from non-violent to violent conflict. Further important limitations of current research are inadequate data (e.g. on rainfall), insufficient indicators (e.g. of drought or conflict independent of violence), and the lack of comparability and generalization for different regional contexts and intermediate pathways. […] Causality is hard to measure as numerous variables, complex interactions, and long chains are involved" (chapter 3, section 3.7).

1.4.3 Climate change can induce a path-dependent process self-reinforcing conflict

In this section, I have combined the analytical framework in Figure 7 with the central intermediate factors extracted from the literature reviews in chapters 2 and 3. In chapter 2, it is mentioned that conflict influences vulnerability, which I use to describe a feedback loop that reinforces conflict once a conflict is present, and which can be triggered or enhanced by climate change. This feedback loop is applicable for potential resource conflicts (for a definition cf. section 1.2.2). Aggression theory (section 1.4.1.8.2) can be applied as well and describes a potential direct climate-conflict effect, which can be enhanced by existing conflicts, too.

A list of central intermediate factors has been extracted from the literature (1.4.2.3) as summarized in chapter 3 from all peer reviewed case studies on the climate-conflict link published between 2004 and 2012. This list of five fundamental intermediate factors is:

- precipitation change and variability
- freshwater resources and scarcity
- land and food
- weather extremes
- environmental migration

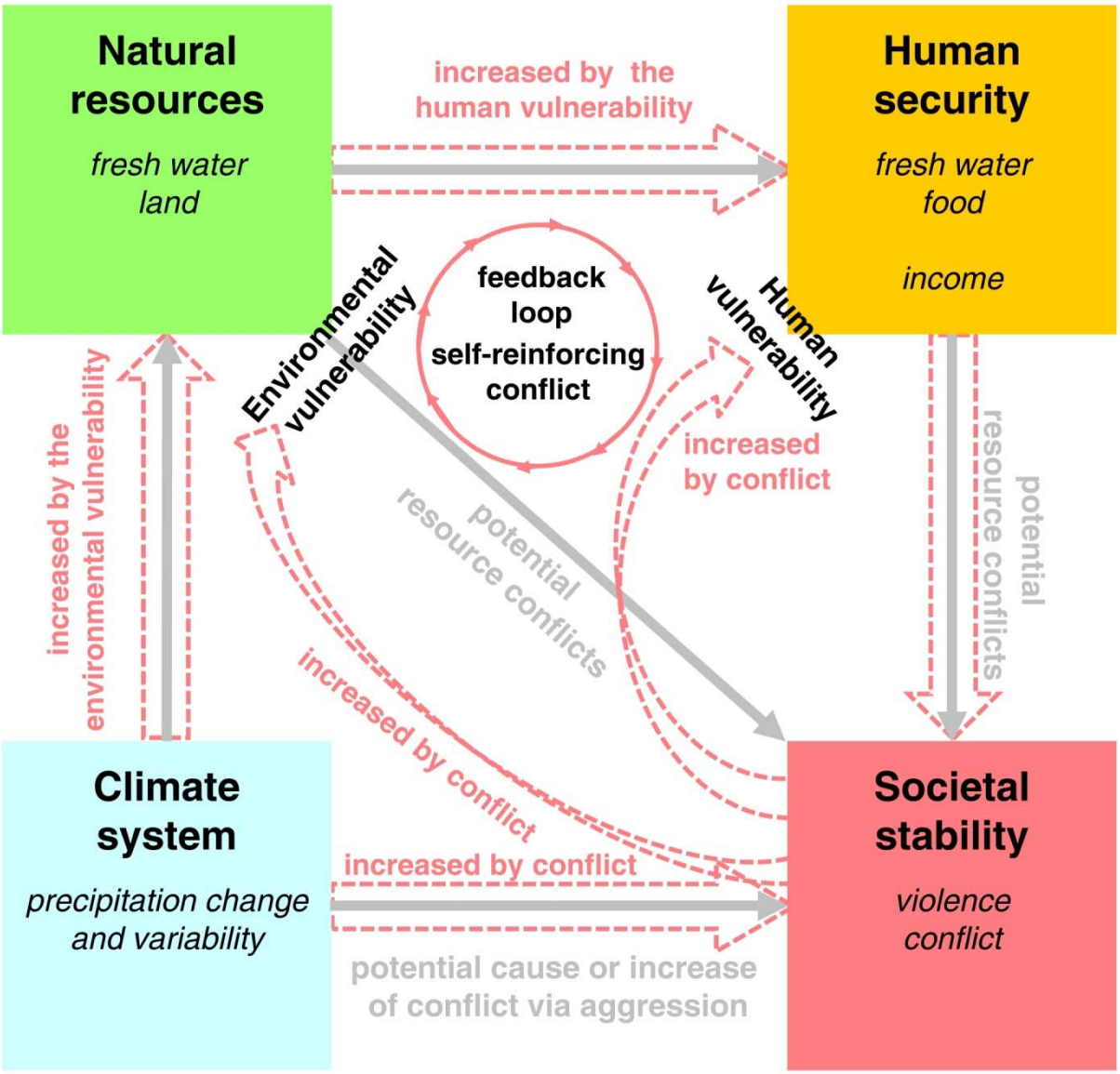

Figure 3 Central intermediate factors in the analytical framework (Figure 7). Marked in red are the potential feedbacks via violent conflict and vulnerability, induced by climate change.

Environmental migration is more seen as an adaptation measure (chapter 3) and therefore rather as an alternative to conflict in some cases at least in the departing country, sometimes supporting the residents who stayed behind via remittances. For weather extremes the credo has been that they might lead to local crises that still require research, whether or not there is a conflict potential because in some cases of crisis cooperation rather than conflict has prevailed. This leaves precipitation change and variability, which can lead to impacts on the availability of freshwater resources and to impacts on land and food production. The associated analyzed conflicts are framed as potential resource conflicts (chapter 3), while

cooperation on a large-scale has been mentioned for freshwater resources referring to the increasing number of international water agreements.

Considering the main sociological conflict theories applied in this dissertation – resource conflict theory and aggression theory – aggression can also be considered to be the result of precipitation changes and variability. According to aggression theory (section 1.4.1.8.2), the presence of weapons or violent conflict increases the likelihood of a person to interpret his or her own feelings after frustration as anger, and thus, the mere presence of weapons or conflict increases the likelihood of aggressive behavior as a reaction to frustrating events, which may be caused by climate change.

In Figure 3, the final three intermediate factors and the conflict potentials have been sketched in the scheme of the complex analytical framework (Figure 7). Afterwards, I have added the potential feedbacks that conflict can have on the vulnerabilities, i.e. the human vulnerability and the environmental vulnerability, via the conflict's potential impacts on the adaptive capacity and the sensitivity to climate change, referring to: "Vulnerability can be broken down into three factors: (i) exposure to climate change, (ii) sensitivity to climate change, and (iii) adaptive capacity (Parry et al., 2007). The last two can be affected by conflict" (chapter 2).

That way, conflict can increase environmental vulnerability, which increases the effect of changes in the climate system on the environmental system. Further down the causal chain, conflict can increase the impact of changes in the environmental system on the human security as well through increasing the human vulnerability. The accumulated impacts can further lead to increased resource conflicts. This causal deduction describes a feedback loop induced by climate change, in which conflict feeds back on increasing conflict and thus self-reinforces conflict. Does this self-reinforcing process of conflict approach a lock-in? There are lock-ins possible for resource conflicts: on the one hand a theoretically trivial lock-in would be reached if the conflicting partners destroyed each other or if only one of them survived. Another lock-in could be reached if the conflict is institutionalized such as the conflict over land between Israel and Palestine. In the first type of lock-in the level of violent conflict escalates up to destruction, in the second type of lock-in, the conflict among the conflicting partners becomes an institution, which can be fought out on various levels without

destroying each other but instead keeping up the conflict even in times of lower levels of intensity of violence.

Consequently, climate change can induce a path-dependent process self-reinforcing conflict. This matches the discussion of climate change being a threat multiplier of existing conflicts rather than causing them initially. But applying aggression theory one way remains how climate change could induce a conflict, i.e. if people react increasingly aggressively due to feeling affected by environmental change (Figure 3, arrow at the bottom directly from the climate system to the social stability).

1.5 Discussion

In this dissertation there is no empirical verification of the deduced path dependence theory included. Just as in Granovetter's theory of weak ties, it is unlikely that studies have already directly observed or asked participants whether they merely practice following behavior. Rather the situation of an experiment or interview would likely encourage participants to rationalize their actions if asked for an explanation of their behavior. Or the researchers are likely to rationalize their observations, like Hedström has rationalized his observations of imitation behavior of drivers into a 'rational imitation' (Hedström & Swedberg, 1998, p. 306ff.). Interestingly, in Asch's legendary conformity experiments (Asch, 1956), there have been participants who followed the majority (consensus) without feeling a necessity to do so. When asked directly they stated that they had not even recognized that the answers that the majority had given were wrong. But this, of course, could only be interpreted as an indication of the advanced path dependence theory to be applicable rather than a verification of the dissemination of the following behavior it describes throughout society.

But the advanced path dependence theory can already be used as an explanatory theory (Coleman, 1964). Its development can also be seen as following the recommendation for a future research agenda in *Climate Change and Society - Sociological Perspectives* (Dunlap & Brulle, 2015a, p. 422): "Extend the analysis of causal chains to include how social forces drive environmental changes and, in turn, how these environmental changes result in further

social impacts […]". Thus, this section discusses the potential impact of path dependence in the overall climate-conflict nexus.

> "Decarbonization of the world's economy would bring colossal disruption of the status quo. It's a desire to avoid that change — political, financial and otherwise — that drives many of the climate sceptics. Still, as this journal [Nature] has noted numerous times, it's clear that many policymakers who argue that emissions must be curbed, and fast, don't seem to appreciate the scale of what's required" (Nature Editorial, 2018).

Why is it such a big effort to change the status quo to reach a lower carbon emission society? Since the industrial revolution, many standards associated with technology – production, logistics, or transport – produce carbon emissions. Additionally, marketing, shopping facilities, or postal services produce carbon emissions, too, to bring together the product and the customer. And even the usage of the product by the customer may produce additional carbon emissions if e.g. electricity is used that stems from non-renewable sources, or if the product needs gasoline to run like cars, tractors, trucks, a gas stove, or tools like a hedge trimmer, a mowing machine, or a leaf blower. And even before the production of a product, the extraction or production of raw materials, production of pre-products and transportation of raw materials and pre-products produce carbon emissions, too. However, this holds true not only for technological products, but for all kinds of commodities, fabrics, their production, transportation, and finally usage by the customer, e.g. when cooking shipped vegetables, washing clothes, cooling orange juice in the fridge, using the smart phone etc. Furthermore, this production chain and correlated amount of emission production is comparably large for the production and usage of all kinds of wrappings – nearly every product for industrial use or consumption is wrapped somehow at delivery – and for toilet articles or tissues you throw away after usage. The garbage collection, the fermentation of waste, recycling, or burning, releases carbon emissions as well. Just like construction work, airplanes, heating systems, and the production of toys do, the usage and cooling of servers for web-applications or Bitcoin calculations produce extraordinary amounts of emissions. A complete list would go beyond the scope of this dissertation.

In the social system, there are many path-dependent processes that reinforce a high carbon emission behavior which causes, stabilizes, and enhances climate change. Additionally, the following discussion analyzes whether climate change itself is path-dependent from a physical perspective considering dynamics of reaching potential tipping elements in the climate system. Then climate change could induce path dependence-induced behavior as deduced and analyzed in the previous sections. How do climate change-induced behavior and path dependence-induced behavior go along together? What can climate change- plus path dependence-induced behavior imply for the climate-conflict nexus?

1.5.1 Is climate change path-dependent?

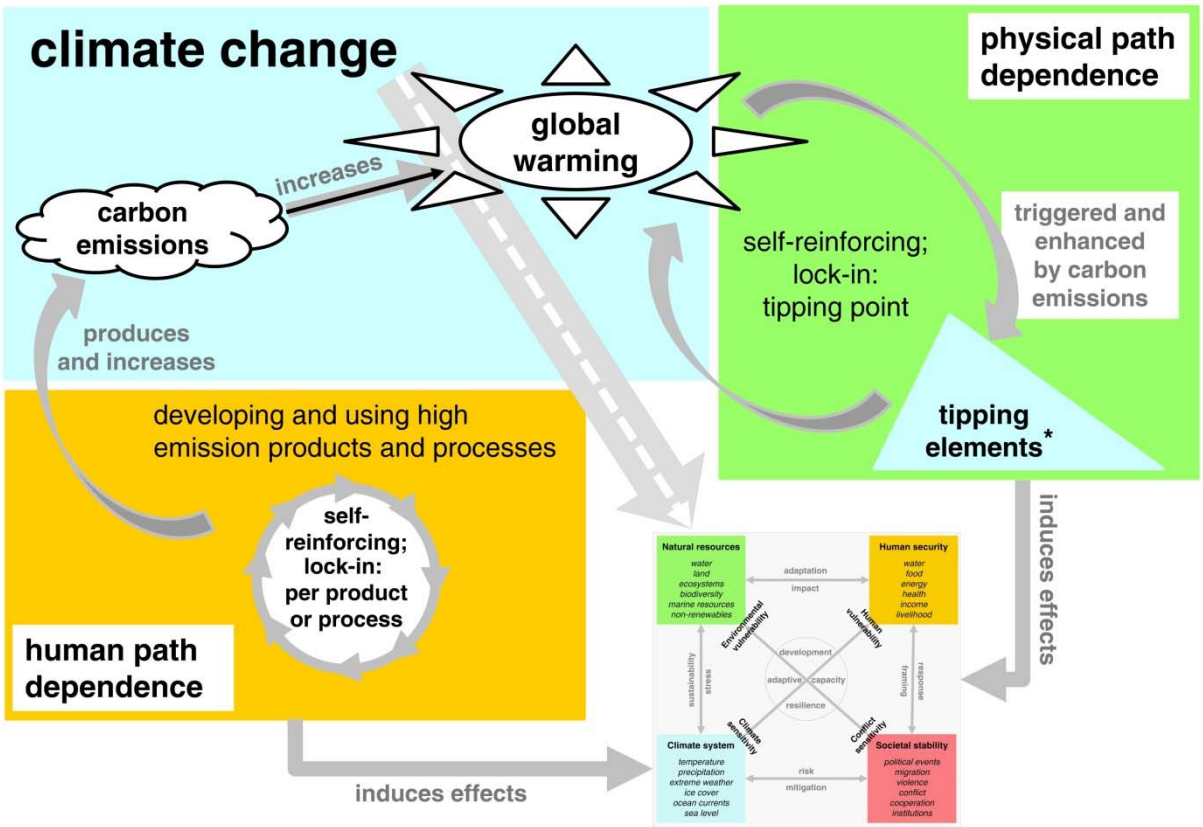

Figure 4 How human path dependence and physical path dependence increase climate change with socio-environmental effects.
(*tipping elements: Not all tipping elements reinforce global warming and not all tipping elements are self-reinforcing. But all tipping points mark a potential lock-in and for each tipping element there is a related tipping point, which it approaches. And some tipping elements are path-dependent reinforcing global warming. All tipping elements are triggered by human emission behavior).

What is the process behind climate change that needs to be analyzed for checking its potential path dependence? Since the beginning of the industrial revolution, carbon emissions, which are the cause of anthropogenic climate change, have increased significantly (Figure 5). The technological carbon emissions are connected to the industrial revolution, which is path-dependent in terms of reactive sequences and the irreversibility of the process (Katz & Shapiro, 1986; Mahoney, 2000). Considering the definition of a path-dependent process as being a self-reinforcing process with the tendency towards a lock-in, I do not know about a state of lock-in that climate change could reach as the process of global warming could go on and on. Partly, the effects of climate change in the climate and environmental system can lock-in, whenever tipping points are reached (Figure 4). And also the human made high emission processes and products and their usage can lock-in so that climate change is always fueled.

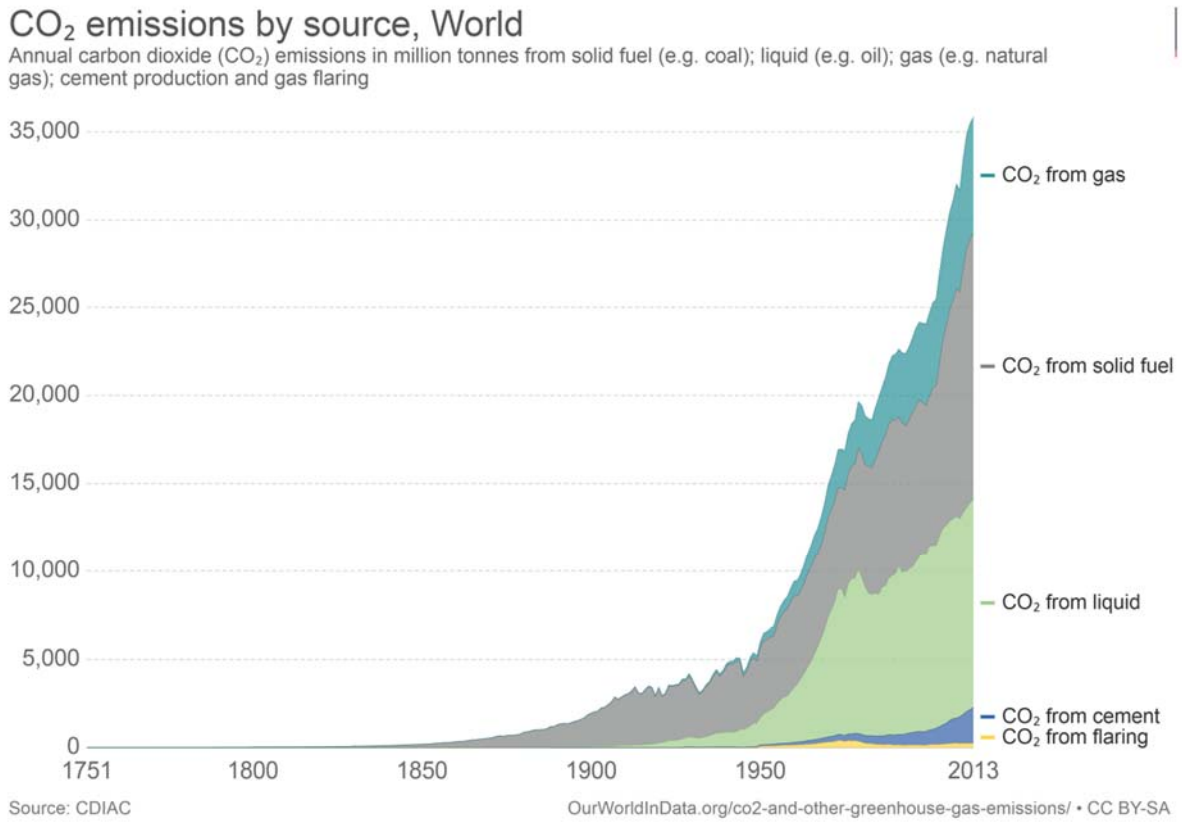

Figure 5 Global annual carbon dioxide emissions since the industrialization. (Carbon Dioxide Information Analysis Center, 2014).

The following section analyzes further how physical path dependence reinforces climate change. Afterwards, human path dependence is considered and how intense carbon emission production appears to be a self-reinforcing process itself even though presumably nobody actually aims at carbon emission production.

1.5.1.1 Physical path dependence

> "Human activities may have the potential to push components of the Earth system past critical states into qualitatively different modes of operation, implying large-scale impacts on human and ecological systems. […] Such phenomena have been described as 'tipping points' following the popular notion that, at a particular moment in time, a small change can have large, long-term consequences for a system, i.e., 'little things can make a big difference' (Gladwell, 2000)" (Lenton et al., 2008)[7].

This description of tipping points in the climate system, in which little things can make a big difference already reminds of the butterfly effect of path dependence (section 1.2.1.3). Furthermore, Lenton and others (2008) describe even more explicitly the role of a critical juncture (Collier & Collier, 1991), the appearance of positive feedback (Arthur, 1994), the occurrence of hysteresis effects, which means that history matters (section 1.2.1.1) (David, 2001; Mahoney, 2000; Pierson, 2000), and bifurcations, which implies that at a critical juncture there are different ways ahead possible. However, once the critical juncture is left the next steps are pre-determined.

> "In discussions of global change, the term tipping point has been used to describe a variety of phenomena, including the appearance of a positive feedback, reversible phase transitions, phase transitions with hysteresis effects, and bifurcations where the transition is smooth but the future path of the system depends on the noise at a critical point. We offer a formal definition,

[7] Even though the paper by Lenton and others is from 2008, it is fundamental in its research on tipping elements and largely cited (2229 citations according to Google Scholar in March 2018).

> introducing the term 'tipping element' to describe subsystems of the Earth system that are at least subcontinental in scale and can be switched - under certain circumstances- into a qualitatively different state by small perturbations. The tipping point is the corresponding critical point - in forcing and feature of the system - at which the future state of the system is qualitatively altered" (Lenton et al., 2008, p. 1786).

Interestingly, the authors consider the process before the tipping point, which denotes the tipping point as the critical moment right before the lock-in, which is the state where nothing can be altered anymore but everything is predetermined even though there may be large dynamics and impacts once the lock-in is reached. Thus, when a tipping point is reached, the fact becomes clear right before it is too late to do anything about it. And since policy would need more time to get involved for potentially changing an unwanted future early enough, it would need to know about a possible approach of a potential tipping point long before the climate system has actually reached it. Therefore, Lenton and others have defined tipping elements (Figure 6), which are systems that may each lead to tipping points of potential interest for scientists and politicians. If the tipping element shows path-dependent processes, it would be more difficult to avoid the tipping point the closer the system gets to the tipping point. So it is important to know about these potential dynamics as early as possible.

Two examples for path-dependent processes in the climate system triggered by climate change and further increasing global warming are the melting of the Greenland Ice Sheet (GIS), and the Arctic Sea-Ice loss. Each reveals a positive feedback process with the tendency towards a lock-in, which is eventually the ice-free situation:

> "[…] in deglaciation, warming at the periphery lowers ice altitude, increasing surface temperature and causing a positive feedback that is expected to exhibit a critical threshold beyond which there is ongoing net mass loss and the GIS shrinks radically or eventually disappears" (Lenton et al., 2008, p. 1789).

> "As sea-ice melts, it exposes a much darker ocean surface, which absorbs more radiation-amplifying the warming. […] Positive ice-albedo feedback dominates

external forcing in causing the thinning and shrinkage since 1988, indicating strong nonlinearity and leading some to suggest that this system may already have passed a tipping point (18), although others disagree (19). […] Given that the IPCC models significantly underestimate the observed rate of Arctic sea-ice decline (17), a summer ice-loss threshold, if not already passed, may be very close and a transition could occur well within this century" (Lenton et al., 2008, p. 1788f.).

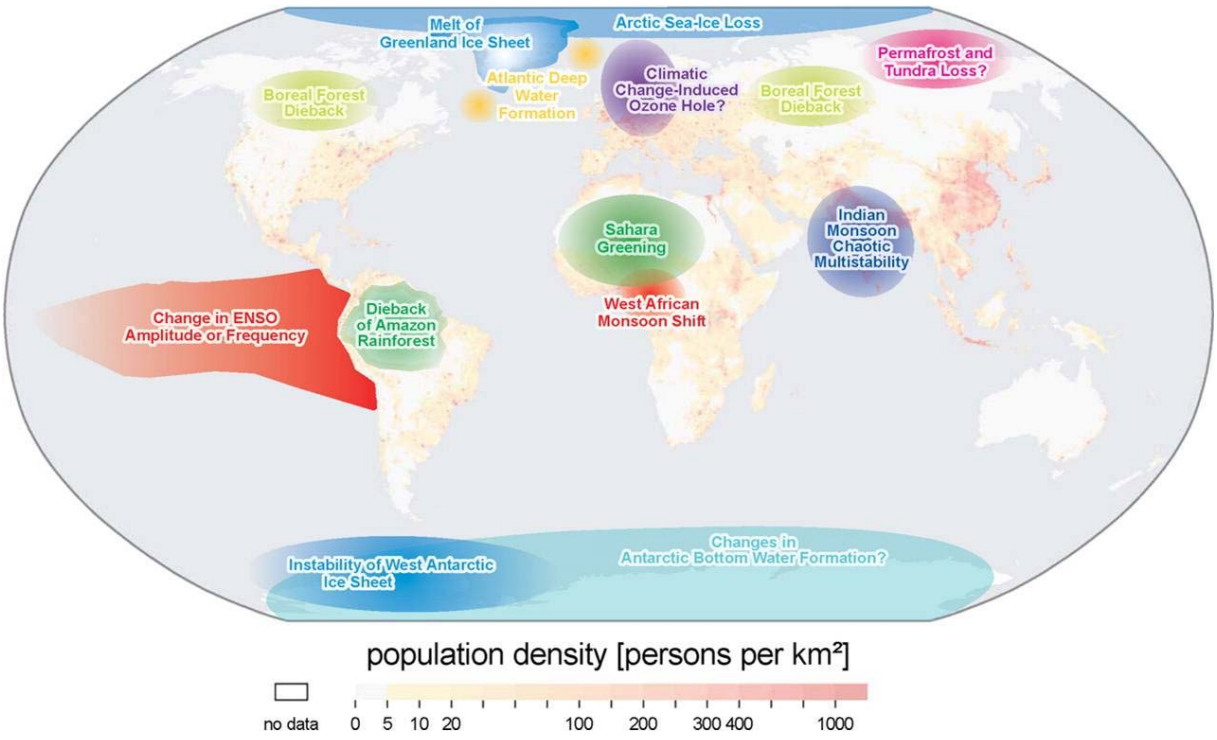

Figure 6 Map of potential policy-relevant tipping elements in the climate system overlain on global population density
(Lenton et al., 2008).

But even though the melting processes of the Greenland ice sheet and the Arctic sea-ice are path-dependent and both are triggered by and reinforcing global warming, there is no state of lock-in that global warming is approaching via these processes.

Besides these effects of global warming that are path-dependent themselves or may trigger path-dependent processes, there are tipping elements that further increase global warming once they are triggered by enough human carbon emissions. In addition to the loss in Arctic summer sea-ice, the increase in tree fraction in the Tundra and losses in marine methane hydrates potentially amplify global warming. But the latter two are presumably far away from a tipping point as their critical thresholds could not yet be defined and especially with regard to the marine methane the transition is so slow that it proceeds over thousands of years.

If carbon emissions are one of the causes and the ongoing carbon emissions one of the mechanisms (Beyer, 2005, 2015) that stabilize the path[8], when is the melting an unstoppable process if people theoretically could change their behavior at any time?

Interestingly, there is even a suggestion for measuring how close a system is to approaching a tipping point (Held & Kleinen, 2004), which is like measuring how close a path-dependent process is to reaching a lock-in[9]:

> "A method is introduced to estimate the proximity of climate sub-systems to non-linear thresholds. We suggest to measure the smallest decay rate of the system under investigation and to consider its trend. We argue that this is the diagnostic variable most directly linked to the distance from a bifurcation threshold" (Held & Kleinen, 2004, p. 1).

To summarize: Physical path dependence in the process of global warming increases the speed of global warming, which makes it more likely to reach tipping points. In the thinking of history matters, large former carbon emissions accumulate in the climate system affecting current and future global warming and its side effects. When tipping points are reached, they lead to an irreversible change in the climate and environmental system. These changes as well as side effects of global warming have potentially severe impacts on people and societies.

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[8] This may perhaps not be a self-reinforcing mechanism because it is unlikely that people's emissions are coupled with the melting of the Greenland ice sheet in a way that they would produce the more emissions the further the melting has proceeded.

[9] Other than in a social system the relevant variables are easier and more reliably measured in the natural system. Alternatively, they can be made available and comparable through complex models.

1.5.1.2 Human path dependence

Anthropogenic climate change is by definition human-made. Human emission behavior by means of carbon emissions or methane induce global warming and trigger and enhance climatic and environmental changes. Is human emission behavior path-dependent? Arthur (1994) has discovered positive feedback processes in economic action and in product shares on markets. And even technological innovation is path-dependent. Since the invention of the assembly line social diffusion with technological products can be self-reinforcing as well. E.g., the more cars are built at once, the cheaper a single one gets, the more people are able to afford a car, the more people buy and drive cars, the more cars need to be built, and so forth. This is a self-reinforcing cycle. The lock-in would be the saturation of society with cars. Thus, anthropogenic climate change is based on at least one path-dependent process, which self-reinforces high emission behavior with the tendency to lock-in into the high emission behavior.

As described, human path dependence increases carbon emissions by reinforcing the usage of high emission products. Additionally, when there is a large share of high emission behavior in society, it takes a comparably long time for human path-dependent structures to switch to low emission behavior (cf. the results of the *SHE-Model*, chapter 6). If some path-dependent processes are close to a lock-in with high emission behavior, the speed of change is very low, even if the environment begins to change towards “low emission behavior is good”. Furthermore, as long as the new “environmental feedback”, which has to switch to “low emission behavior is good”, is not entirely diffused, path dependence reinforces people to rather to stick to what they are doing (persistence, cf. section 1.2.1.2) than to change their behavior, especially as long as the others which they follow do not change their behavior (PDSNs, cf. chapter 5). People who allow for the induction by path dependence are led by the topics of the ones they follow, which up to now are generally not climate change, path dependence, or how to change one’s emission behavior.

1.5.2 Does path dependence in the climate-conflict nexus induce conflict?

Physical path dependence increases the effect of climate change by reinforcing climate change, which indirectly increases the effect of people's emission behavior on climate change when triggering physical path dependence. Accordingly, this also increases the effect of climate change on environment, society, and potential conflicts (compare Figure 3).

Human path dependence increases the likelihood of people to act like an ideal type path-dependent agent, which is to follow others (section 1.4). Merely academically, in a group of only ideal type path-dependent agents this would lead to consensus, which would imply cooperation instead of conflict (section 1.4.1.7). But in real life path dependence reinforces the existing consensus or conflicting structures (section 1.4.1.8). The more people allow the induction by path dependence the more likely people locally practice swarming behavior, which may support low level conflicts when increasing the polarization (both sides form in hierarchies or gather in groups). Due to the general influence from path dependence, people are more likely to allow path dependence to influence their behavior, which can be to support the positive feedback loop for the self-reinforcing resource conflicts (cf. Figure 3). Aggressive behavior can diffuse via PDSNs and swarms, which potentially increases the overall effect of even single uncorrelated occasions of aggression (sections 1.4 and Figure 3). Cascades like butterfly effects are possible via PDSNs and can transfer conflict or potentially even consensus to different regions or topics.

1.6 Conclusion

"We are human beings and we need more than economic comfort.
We need challenge, we need meaning, we need purpose,
we need alignment with nature."
(W. Brian Arthur , 2009: *The Nature of Technology*, p. 216)

Of course, in real life behavior is not predictable as people could always just change their behavior if they knew about the prediction. But if people allow path dependence-induced behavior, they consent to being predictable to some extent. This corresponds to people

allowing to be traceable via GPS when installing a weather app on their smartphones. Some may stop short asking themselves whether they really want to give away their personal position data but once installed they get used to it and do not think about the consequences any longer. But how do people behave when they are induced by path dependence? This dissertation advances existing path dependence theory using the methodology of mathematical sociology. The result is a number of theorems on path dependence-induced behavior mostly for an ideal type path-dependent agent or a group of ideal type path-dependent agents, which are mathematically sociologically proven to be logically rigorous based on fundamental sociological theories. Ideal type path-dependent agents follow each other or the masses, which is analyzed in egocentric path-dependent social networks (PDSNs), and in an agent-based model in which swarming and herding agents are affected by an environment (*SHE-Model*). Thinking of connected PDSNs allows the explanation of trans-sectorial and trans-regional cascades. Further induction by path dependence reduces the number of outgoing links or reinforces the exact same following behavior (as following the majority of all) for each PDSN, which brings agents to practicing more simple swarming or herding behavior. Simulations with the *SHE-Model* reveal self-reinforcing opinion dynamics with the tendency towards a lock-in, which is path dependence. This demonstrates the closeness of the extended path dependence theory through the *SHE-Model* simulations of ideal type path-dependent agents. Thus, path-dependent behavior leads to path dependence, which further induces and reinforces behavior. In these path-dependent opinion dynamics simulated by the *SHE-Model*, the agents are the slower in adapting to a changing environment the closer they are to a lock-in. Finally, it is proven mathematically sociologically that each institutionalization is path-dependent, which proves mathematically sociologically that every social person in real life is at least influenced by path dependence.

The transfer to real life behavior is not easily made but the more a person is affected by path dependence, the more it is induced to act like an ideal type path-dependent agent, which is basically practicing following behavior. Thus, if the person allows the induction by path dependence to occur, path dependence transforms his or her behavior increasingly into path-dependent behavior. And the developed theory is applicable. Consequently, if the person allows the induction, the person tends to practice following behavior when being confronted with new situations. Over time the person tends to practice following behavior in other situations as well. Social networks, in which the following behavior takes place, tend to become less important over time leaving only a few personal experts for each possible topic

or asking the masses otherwise. When allowing the induction, people tend to increasingly form in swarms or build hierarchies, allowing for spontaneous or organized mass dynamics. Within an interconnected group of followers path dependence induces consensus. But at the border to non-followers, path dependence can induce and reinforce conflicts.

Furthermore, path dependence theory is applied to the climate-conflict nexus. A literature review reveals that it is ambivalent whether or not climate change induces conflict. A new analytical framework visualizes the complexity of the interactions of the climate system, the societal system, the human system and the environmental system, emphasizing vulnerabilities and sensitivities. Based on a literature review, a self-reinforcing feedback loop is drawn within the analytical framework, which reinforces conflict induced by climate change. This supports the general argument that climate change may function as a threat multiplier of existing conflicts. Via aggression theory it is argued that climate change can also initially trigger conflicts and those effects are more likely to occur with increasing climate change and increasing general presence of conflicts.

Combining the path dependence and climate change perspectives, it can be asked whether climate change itself is path-dependent. While the author does not know a state of lock-in that climate change would approach, there are many human made path-dependent processes that produce carbon emissions as side effects and which are close to a lock-in and self-reinforcing, thus pushing emissions and climate change with a strong and increasing intensity. Furthermore, physical path dependence is analyzed when including tipping elements with potential tipping points as lock-ins. In conclusion, the assessment of what behavior climate change and path dependence induce together reveals that within the climate-conflict nexus path dependence generally functions as a multiplier for conflicts or consensus, whatever is already there, and also for the environmental and further induced social effects via physical path dependence. As the reinforcing presence of path dependence increases the likelihood of people allowing path dependence to induce their behavior, even initially small conflicts could spread via path-dependent social networks or swarming behavior. The closer a path-dependent process is to a lock-in, the slower and lower is the ability to adapt to a changing environment. Thus, path dependence reduces the adaptive capacity and increases the vulnerability to climate change. But even though each institutionalization is path-dependent,

institutions that fully adapt to climate change by mitigation or adaptation efforts may increase the overall speed of mitigation or adaptation.

This cumulative dissertation uses mathematical sociology in a new way to develop an innovative path dependence perspective of agency, which is combined with conflict and consensus theories and applied to the climate-conflict nexus. The result is a mathematically sociologically rigorous analysis of historical, current and potential future behavior, which is induced by path dependence and applied in the context of climate change. While statistical analyses may produce new extrapolations every millisecond in the era of massive big data, this mathematical sociological analysis of induced social behavior allows to get an idea on what dynamics prevail in a new situation, a situation of change. The new focus looks at the underlying social dynamics rather than merely extrapolating data points. The dissertation shows that even in areas with large complexity and large uncertainty an extensive logical thinking can reveal interdependencies and an understanding of dynamics that can be helpful in connecting disciplines, shaping future research and potentially even societal or political action.

1.7 Overview of the following chapters

1.7.1 Chapter 2: Climate Change and Violent Conflict

Does climate change cause violent conflict? Current debates on the climate-conflict nexus originate in a lack of data as well as the complexity of the interconnections of the two phenomena. A new analytical framework visualizes the complex interacting effects of the climate system, the environmental system, human security, and societal stability. This is used as basis for defining future research challenges on each of the interactions, allowing the assessment of effects of the social systems on climate change. Given that the reviewed research is ambiguous about the effect of climate change on conflict, a crucial aspect is the existence and availability of respective datasets that differ in the definition of conflict, region, and time scale. The debate on securitization could reinforce the likelihood of violent conflict. Other responses to climate change may also become causes of conflict, including bioenergy, nuclear power, or geoengineering.

1.7.2 Chapter 3: Disentangling the Climate-conflict Nexus: Empirical and Theoretical Assessment of Vulnerabilities and Pathways

In a comparative literature review the results of peer reviewed quantitative papers published between 2004 and 2012 are classified with help of a number of criteria such as specified climate-conflict link, conflict type, region, analyzed period and data used to carve out differences and similarities. Searching for the actual potential mechanisms that lead from climate change to conflict, causal pathways such as precipitation changes, freshwater scarcity, food insecurity, weather extremes, and environmental migration are analyzed. As there is no consensus found on the climate-conflict nexus, an additional methodological approach develops and applies a model of greater complexity, distinguishing various pathways of interaction between climate change, the environment, and human society. This is applied to an analysis of state-based vulnerability, climate, conflict, development, economic, and natural disaster data. A geographic differentiation indicates that countries with low human development are particularly vulnerable to the double exposure of natural disasters and armed conflict.

1.7.3 Chapter 4: Global climate policy reinforces local social path dependent structures: More conflict in the world?

The official problem: the prevention of climate change and mitigation of negative effects on society and the environment. But conflict may result as a side effect of debating, communicating, and implementing policies aimed at the prevention, mitigation of, and adaptation to climate change. In a new model frame, path dependence theory is advanced to consider agency, which is applied to each step of an overall problem solving process, assuming that all the time the involved agents are affected by path dependence. An expanded multi-agent model demonstrates that, via path-dependency effects, decisions at the global level can result in a reduction of the variety of action applied locally. This perception of diminishing options can coincide with an increasing radicalization of positions and a reinforced strengthening of existing social hierarchies. Thus, global climate policy can lead to an intensification of national and local conflicts around the world.

1.7.4 Chapter 5: Cascading Processes and Path Dependency in Social Networks

Expanded path dependency theory is used to combine social network theory and the concept of cascading events. This theory of path-dependent social networks (PDSNs) is applied to three examples: the case of the Fukushima earthquake and its social effects on German politics, the case of the Arabian Spring and demonstrations in Egypt, and the case of climate change and potential cascades and tipping points in climate-society interaction. A new situation threatening a group of people can have different effects: Such challenges can result in reinforcing social structures that enable people to increase speed, self-effort and altruism in order to reach a group's survival as in a disaster. However, it can also result in competing and fighting structures as in the example of the revolutionary developments in the Arabic countries. But in all cases the actions reinforce path-dependent social structures and thus the likelihood of social cascades.

1.7.5 Chapter 6: Local approximation of path-dependent behavior: *the SHE-Model*

Can path-dependent behavior be locally approximated, close to a lock-in? Using mathematical sociology, path dependence theory is further advanced. Now, in an agent-based model, a group of ideal type path-dependent agents who perform a following behavior is simulated: swarming and herding agents affected by an environment (*SHE-Model*). Assessments of the model runs reveal that the opinion dynamics simulated with the *SHE-Model* are self-reinforcing with the tendency towards a lock-in, thus path-dependent. This path dependence again affects involved agents. Therefore, in a path-dependent process the effect of path dependence on involved agents increases over time. The more a person is affected by path dependence, the more likely the person acts like an ideal type path-dependent agent and the more likely a group of affected persons acts in dynamics like simulated with the *SHE-Model*. Consequently, close to a lock-in, the path-dependent behavior can be approximated by the *SHE-Model* dynamics.

1.7.6 Chapter 7: Each institutionalization elementary is a self-reinforcing process increasing path dependency

How are path dependence theory and institutionalism linked? The hypothesis of this paper is that each institutionalization is path-dependent, for a neo-institutional understanding of an institution and the definition of path dependence as: A self-reinforcing process with a tendency towards a lock-in. Based on the assumptions that Berger and Luckmann's theory of primary and secondary socialization holds true and Giddens' duality of structure is valid as well, a process oriented perspective is taken focusing on the process of the institutionalization of an institution with involved and affected persons. The dynamical steps are considered from the very start of the institutionalization when the institution begins to exist, which reinforces back on the involved persons inducing a further institutionalization, which leads to a strengthening of the later institution, which enhances the self-reinforcing institutionalization. That way the hypothesis is proven mathematically sociologically, which contributes to advanced mathematical sociology.

2 Climate Change and Violent Conflict

Jürgen Scheffran, Michael Brzoska, Jasmin Kominek, P. Michael Link & Janpeter Schilling

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Current debates over the relation between climate change and conflict originate in a lack of data, as well as the complexity of pathways connecting the two phenomena.

Since publication of the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), the debate on the security implications of climate change has intensified. Research in this area has made progress but remains controversial (for recent reviews see (Bernauer et al., 2012; Buhaug & Theisen, 2012; Gleditsch, 2012; Scheffran et al., 2012a). Although some quantitative empirical studies support a link between climate change and violent conflict, others find no connection or only weak evidence.

A major challenge for all studies is to find adequate data. Instead of using data on the long-term average and variability of temperature, precipitation, and other climatic variables that would clearly fall under the IPCC definition of climate change (Solomon, 2007), many studies have used proxies, such as short-term data on weather and extreme weather events, or on natural phenomena of climate variability like the El Niño Southern Oscillation (Hsiang et al., 2011).

It is important to distinguish between the types of conflict used in various datasets. The widely used Armed Conflict Dataset of the Uppsala Conflict Data Program and the Peace Research Institute Oslo (UCDP-PRIO), for instance, sets a minimum of 25 battle-related deaths per year and involvement of at least one state government to be considered as armed conflict (Themnér, 2011). This excludes other forms of violent or non-violent behavior that

may be affected by climate change such as protests, riots, or livestock theft, let alone conflict as a positional difference over interests, values or goals. These distinctions are relevant as, in recent decades, climate variability may have been more associated with low-level violence and internal civil war – which fall below the UCDP/PRIO definition cutoff – than with armed conflict or war between countries.

Long-term historical studies tend to find a coincidence between climate variability and armed conflict, in line with some narratives about the evolution and collapse of civilizations (e.g. Kuper & Kröpelin, 2006). For instance, Zhang and others (2011) combine a set of variables for the period 1500–1800 to identify climate change as a major driver of large-scale human crises in the Northern Hemisphere. Tol and Wagner (2010) cautiously conclude that, in pre-industrial Europe, cooler periods were more likely to be related to periods of violence than warmer phases. Similar findings have been presented for eastern China (Zhang et al., 2007).

However, the results have been less conclusive for recent periods. For instance, in one study, a significant correlation between temperature and civil war in Africa between 1981 and 2002 is used to project a substantial climate-induced increase in the incidence of civil war in Africa until 2030 (Burke et al., 2009). Yet, this result is not robust for an extended time period and alternative definitions of violent conflict (Buhaug, 2010).

Food insecurity has been found to contribute to violence, as exemplified by recent "food riots" (Johnstone & Mazo, 2011; Messer, 2009), but there is little empirical evidence that climate variability is an important driver of violent land-use conflicts – e.g., in the Sahel (Benjaminsen et al., 2012). In Kenya, changing rainfall patterns have the potential to increase resource scarcity as a driver of pastoral conflict (Opiyo et al., 2012). However, more conflict in the form of violent livestock theft is reported during the rainy season than during drought (Adano et al., 2012).

Similarly, conflicts over shared river systems have been associated with low-level violence, yet full-scale wars are unlikely (e.g. Bernauer & Siegfried, 2012; Brochmann & Hensel, 2009). Instead, an increase in international water agreements has been observed (de Stefano et al., 2012).

Finally, some studies suggest that natural disasters related to extreme weather conditions substantially increase the risk of intrastate conflict (Nel & Righarts, 2008). In contrast, Bergholt and Lujala (2012) find no increased likelihood of armed civil conflict due to weather-related disasters, and Slettebak (2012) observes that, in crisis, cooperation frequently prevails.

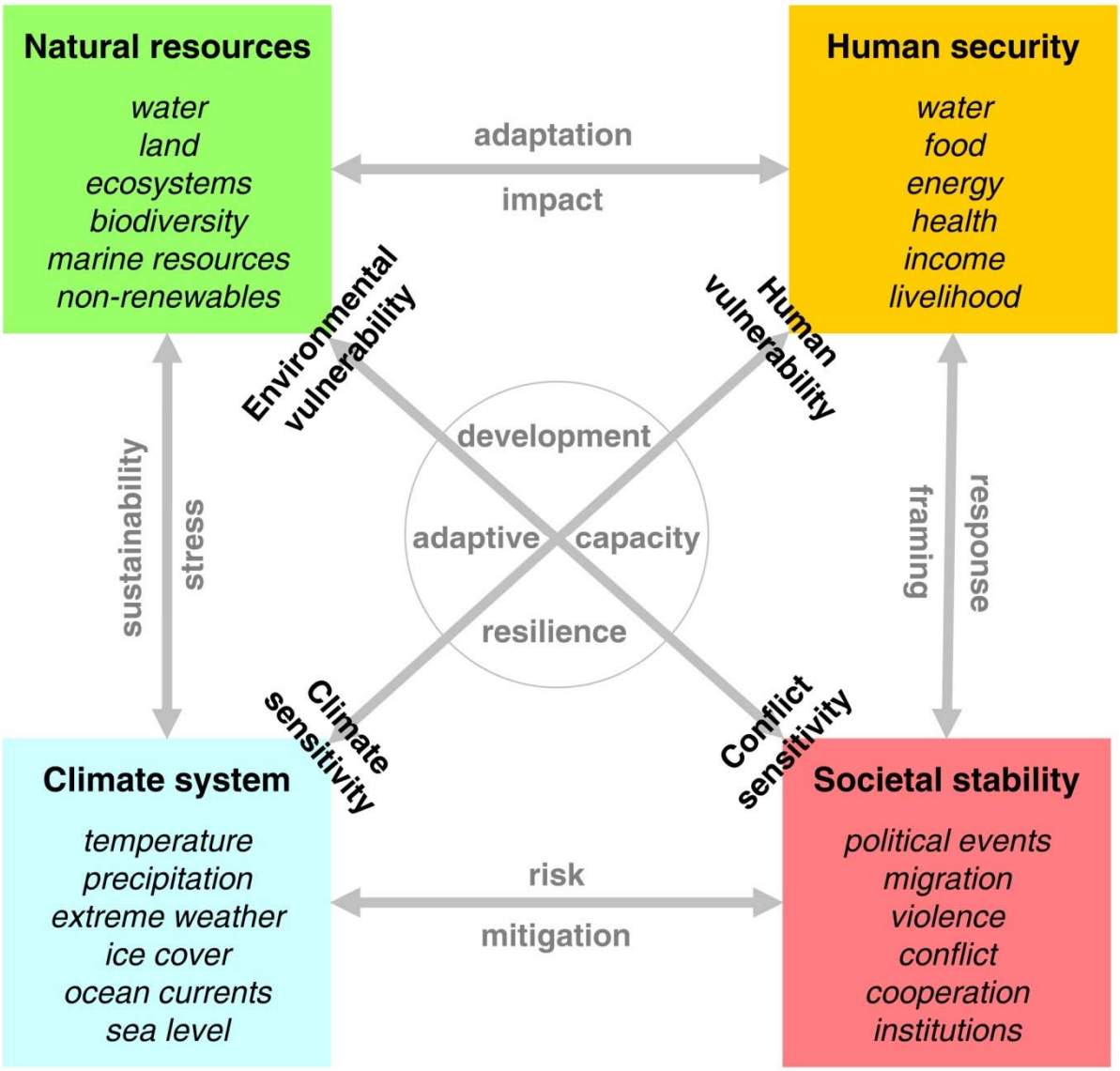

Figure 7 Analytical framework of linkages between the climate system, natural resources, human security, and societal stability
(based on Scheffran et al., 2012c)

New research is on the way as new databases on nonstate conflicts, low-level violence, social instability events, and geo-referenced spatio-temporal patterns become available (Busby et al., 2012; Nardulli & Leetaru, 2012; Raleigh & Kniveton, 2012) and Table 5 in the Appendix). In addition to data needs, it is important to account for complexities in the relation between climate change and conflict. There are multiple pathways and feedbacks between the climate system, natural resources, human security, and societal stability (Figure 7).

Since the 1990s, there has been an extensive scientific debate on how the scarcity of natural resources affects violence and armed conflict (Bächler, 1999; Homer-Dixon, 1994). More recently, conflict studies pay attention to the vulnerability of natural and social systems to climate impacts (Scheffran & Battaglini, 2011). Vulnerability can be broken down into three factors: (i) exposure to climate change, (ii) sensitivity to climate change, and (iii) adaptive capacity (Parry et al., 2007). The last two can be affected by conflict. Many of world's poorest people are exposed to various risks to life, health, and well-being. If climate change adds to these risks, it can increase humanitarian crises and aggravate existing conflicts without directly causing them.

The question is whether human development, resilience, and adaptive capacity can compensate for increasing exposure and sensitivity to climate change. In previous decades, humanitarian aid, development assistance, and wealth per capita have increased (OECD, 2012), which has contributed to a reduction of global poverty as a possible driver of conflict. International efforts to prevent and manage conflicts have also been strengthened, and the number of armed conflicts has declined since the end of the Cold War (Themnér & Wallensteen, 2011). In recent years, however, this trend slowed down or is being reversed. While the number of democratic states has grown over the past half-century, the number of fragile states with weak institutions has also increased (Marshall et al., 2011).

If the debate on the securitization of climate change provokes military responses and other extraordinary measures, this could reinforce the likelihood of violent conflict. Main aspects of security concern include interventions in fragile states, the securing of borders (e.g., against disaster refugees), and access to resources (e.g., in the Mediterranean or Arctic region (see

Brzoska, 2012). Other responses to climate change may also become causes of conflict, including bioenergy (whose producers compete for land and food-related resources), nuclear power (which can lead to nuclear weapons proliferation), or geoengineering (through disagreements between states). Thus, there is a need for conflict-sensitive mitigation and adaptation strategies that contain conflict and contribute to cooperation via effective institutional frameworks, conflict management, and governance mechanisms.

Research challenges

	Effect: Climate change	**Effect: Natural resources**	**Effect: Human security**	**Effect: Societal stability**
Cause: Climate change	Which climate feedbacks enhance or dampen the speed of climate change? Where are thresholds and tipping points?	How are water, land, and biodiversity affected by climate change, e.g., by drought, soil erosion, or flooding?	How do extreme weather and climate variability affect human livelihoods, health, income, and assets?	How does extreme weather affect social conflicts? How can research scenarios of impacts inform politics?
Cause: Natural resources	How do losses of natural resources affect climate change, e.g., through deforestation, ocean uptake, or desertification?	Are there relevant natural adaptation or substitution processes for the loss of natural resources?	How does resource availability affect human security? How to increase resilience and adaptive capacity?	Is conflict triggered by resource abundance or degradation? Does societal stability depend on natural resources?
Cause: Human security	Under which conditions do gains or losses of human security drive climate change and mitigation?	How does human (in-)security affect the use of natural resources? Does a decline in production reduce resource inputs?	Do elements of human (in-)security reinforce each other? Will security risks spread to neighbor regions?	Does human insecurity drive cooperation or conflict? Will human responses lead to social transformation?
Cause: Societal stability	How do social unrest and violent conflict affect carbon emissions? Will social stability lead to climate mitigation?	How does societal stability affect resource exploitation? Can cooperation protect resource stocks?	How do conflict, societal instability, and cooperation affect human security and vulnerability?	Under which conditions do societies (de-) stabilize themselves or solve conflicts? What is the role of institutions?

Table 1 List of core research questions structured by the relationships between causes (vertical) and effects (horizontal) of the human-environment interaction.

The balance between political and social factors and climate change could shift when global temperature reaches levels that have been unprecedented in human history. There is reason to believe that such a change might overwhelm adaptive capacities and response mechanisms of both social and natural systems and thus lead to "tipping points" towards societal instability and an increased likelihood of violent conflict (WBGU, 2009).

Although some fundamental issues have been raised in previous research, numerous interdisciplinary questions still need to be investigated to understand the feedback loops involved (Table 1). Models of the various linkages can build on a rich set of tools from complexity science, multi-agent systems, social-network analysis, and conflict assessment to extend previous data and experiences into future scenarios that cover different social, economic, and political contexts (Scheffran et al., 2012c). Research across scientific disciplines will be needed to identify opportunities and coherent strategies to address societal challenges related to climate change.

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3 Disentangling the Climate-conflict Nexus: Empirical and Theoretical Assessment of Vulnerabilities and Pathways

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Abstract

Recent research has provided new insights into the relationship between climate change and violent conflict. In this review we compare the results, methodologies, and data applied in the peer-reviewed literature to recap the current state of the debate. While long-term historical studies suggest a coincidence between climate variability and armed conflict, empirical findings are less conclusive for recent periods. Disentangling the climate-conflict nexus, we discuss causal pathways such as precipitation changes, freshwater scarcity, food insecurity, weather extremes, and environmental migration. A geographic differentiation indicates that countries with low human development are particularly vulnerable to the double exposure of natural disasters and armed conflict. Thus, effective institutional frameworks and governance mechanisms are important to prevent climate-induced conflicts and to strengthen cooperation. Applying an integrative framework connecting climate change, natural resources, human security, and societal stability, we pinpoint future research needs.

Keywords

climate change, human security, integrative framework, societal stability, violent conflict, vulnerability

3.1 Introduction

While recent research has provided new insights into the relationship between climate change and violent conflict (Gleditsch, 2012; Scheffran et al., 2012b/chapter 2 of this thesis) there is no consensus yet in the literature about its nature and extent. Those who claim a strong causal connection are facing serious doubts by scholars who find no or only weak empirical evidence for such claims. In this literature review we summarize the current state of the debate by addressing the following research questions: Do peer-reviewed studies find significant linkages between climate change and violent conflict? Which factors are found to be of particular importance? What methodologies and data are used in the studies? What conclusions can be drawn from the analysis of the studies? What future paths of research on the linkages between climate change and violent conflict appear to be particularly promising?

While long-term historical studies suggest a coincidence between climate variability and armed conflict, empirical findings are less conclusive for recent periods. Understanding the different views provides a foundation for the prediction of future impacts on violent conflict. However, it is argued here that more comprehensive approaches are needed to disentangle the complex climate-conflict nexus. We briefly discuss the key intervening variables and causal pathways between precipitation changes, freshwater scarcity, and food insecurity as well as weather extremes and environmental migration. Pathways may differ in their relevance for distinguishable types of violence and regional contexts. Theoretical insights suggest that low-level violence is more likely to be linked to the effects of climate change than full scale wars. Empirical findings indicate that climate-conflict linkages vary significantly between the world's regions. For illustration, we provide a broad-brush geographic differentiation by countries to show that countries with low human development are particularly vulnerable to the double exposure of natural disasters and armed conflict.

This highlights the point that climate change is not the only important parameter of future violence. Other factors such as human development, effective institutions, and governance also affect the likelihood of violent conflict. Economic, political, and social factors on local, regional and global levels are interlinked with broader effects of climate change. As a promising basis for future research, we suggest an integrative framework of the pathways between climate change and violent conflict that can be applied to model and empirically

calibrate linkages between climate change, natural resources, human security, and societal stability.

This review summarizes key lessons from the scientific literature, identifies research needs, and draws conclusions for future research and policy. After introducing our methodology, we systematically assess the current state of empirical research on the link between climate change and violent conflict. Going beyond the mere use of global data sets we consider selected intermediate pathways and address regional differences in how climate change and violent conflict affect human security. In this context, the role of human development and institutional processes in multiplying or minimizing potential conflicts is discussed. Finally, we identify shortcomings, challenges and questions for future research within the integrative framework of human-environment interaction.

3.2 Methods

Because of the complexity of the research matter, this article utilizes two research methods. The primary focus is on a comparative review of the scientific literature on the linkages between climate-related indicators and data on violent conflict using large-n designs. To come to conclusions about the effect of climate change on violent conflict with validity beyond single cases, we limit the analysis to (quantitative) empirical studies using regression analysis based on conflict and climate data because of their increasing importance in the recent debate and the difficulties associated with the comparison of (qualitative) field-research studies. We analyze the results of recent relevant studies, classifying them with the help of a number of criteria such as specified climate-conflict link, conflict type, region, analyzed period (Table 2) and data used to carve out differences and similarities. We limit the analysis to studies published since 2004 and accept their academic credibility as articles published in peer-reviewed scientific journals.

As we show, there is no consensus in the quantitative literature regarding the effect of climate change on violent conflict. Since the assumption of a direct link is disputable, we proceed to a second methodological approach, the development and illustrative description of a model of

greater complexity, distinguishing various pathways of interaction between climate change, the environment, and human society. This second method comprises an analysis of state-based vulnerability, climate, conflict, development, economic, and natural disaster data. We identify both the various climate-related phenomena as well as the geographic regions that may be of particular importance for the future study of the links between climate change and violent conflict.

We illustrate the importance of the proposed model of the intermediate factors and indirect pathways between climate change and conflict with some readily available data and relevant literature including recently published studies of our own. To show the geographical distribution of vulnerabilities we relate an established indicator of climate change vulnerability and the most widely used global dataset on conflicts (Figure 9, see following section). We also plot data of battle-deaths against the deaths of (potentially) climate change related natural disasters and the level of human development (Figure 10), which to our knowledge is done for the first time in a peer-reviewed publication. To show how temperature, per capita gross domestic product, the number of violent conflicts, the number of democratic countries as well as battle and disasters deaths have evolved over time, we combine the respective data in a comparative overview (Figure 11) .

3.3 Empirical Findings

Until now, research on the climate-conflict nexus has largely relied on quantitative methodologies based on statistical analyses of climate and conflict data and on qualitative assessments of causal mechanisms in case studies. In contrast to the extensive modeling in climate science, models of climate-conflict linkages are rare (example in Devitt & Tol, 2012; see review in Scheffran et al., 2012c). Using different concepts of climate change and conflict, most studies in this field are based on a selected set of climatic or weather-related variables (temperature, precipitation, and extreme weather events) that are correlated with specific aspects of violent conflict (particularly the onset or number of armed conflicts).

Quantitative empirical research that analyzes various regions and time periods reaches differing conclusions about the influence of climate variables on armed conflict (Table 2). Studies that use quantitative data over long historical periods generally tend to find a correlation between climate variability and armed conflict. One study that shows such a link for pre-industrial Europe concludes that cooler periods in pre-industrial Europe are more likely related to periods of violence than warmer phases (Tol & Wagner, 2010). The authors support their conclusion by referring to a regression analysis that confirms the positive correlation between cooler periods and the higher war frequency and intensity. Similar results have been found for the Northern Hemisphere (Zhang et al., 2011) and Eastern China (Zhang et al., 2007) and are listed in Table 2.

As shown in Table 2, studies for more recent periods come to differing and sometimes opposing results. In an important study, Miguel and others (2004) have found that an increase of armed conflicts was correlated with economic shocks, for which rainfall variation has been used as an instrumental variable in agriculturally-dependent regions in Africa that can be influenced by climate change. However, the specification of rainfall measures has been criticized because of its counterintuitive formalism (Ciccone, 2011). In another major study, a significant linkage between civil war and temperature has been found for the period 1981 to 2002 in Africa (Burke et al., 2009). This study in turn has been challenged on the basis that the results were not robust to alternative model specifications and the application of more recent data (Buhaug, 2010). In what is probably the strongest but also most puzzling statement of a statistical correlation between weather-related data and armed conflict, Hsiang and others (2011) find a strong effect of the El Niño Southern Oscillation (ENSO) on armed conflict for the period 1950–2004. The "probability of new civil conflicts arising throughout the tropics doubles during El Niño years relative to La Niña years" (Hsiang et al., 2011, p. 438). Yet, key questions remain on the connection between climate change and the El Niño phenomenon (Gergis & Fowler, 2009), even more on the link to conflict. Is El Niño an adequate indicator for the impact of climate change on violent conflict? Is it possible that El Niño redirects civil conflict away from La Niña years without raising the overall number of conflict incidences? What are the main pathways of the effects of El Niño years on civil conflict? For low-income countries the study leaves open "if (1) they respond strongly because they are low-income, (2) they are low income because they are sensitive to ENSO, or (3) they are sensitive to ENSO and low income for some third unobservable reason" (Hsiang et al., 2011, p. 440).

link	specified link	conflict type	region	period analyzed	reference
Y	+T | -P | +D →+C	s	global	1950–2004	(Hsiang et al., 2011)
Y	-L→+C	s	global	1980–92	(Theisen, 2008)
Y	-L→+C	s, ns	global	1990–2004	(Raleigh & Urdal, 2007)
Y	+D→+C	s	global	1950–2000	(Nel & Righarts, 2008)
Y	+D→-C	s	global	1950–2008	(Slettebak, 2012)
Y	ΔP→+C	s	Africa	1981–1999	(Miguel et al., 2004)
Y	+P→+C	s	Africa	1990–2008	(Hendrix & Salehyan, 2012)
Y	+P→+C	ns	East Africa	1950–1994/ 1971–2010	(Adano et al., 2012)
Y	+P→+C	ns	East Africa	1989–2004	(Theisen, 2012)
Y	ΔP→+C	s, ns	East Africa	1997–2009	(Raleigh & Kniveton, 2012)
Y	+V→+C	s	East Africa	2000–2006	(Rowhani et al., 2011)
Y	+T→+C	s	SSA	1981–2002	(Burke et al., 2009)
Y	-P→+C	s, ns	East Asia	220BC–1839AD	(Bai & Kung, 2011)
Y	-T→+C	s	East Asia	AD10–1900	(Zhang et al., 2010)
Y	-T→+C	s	East Asia	800BC–AD1911	(Zhang et al., 2007)
Y	-T→+C	s	Europe	1500–1800	(Zhang et al., 2011)
N	+T⊠C	s	global	1816–2000	(Gartzke, 2012)
N	ΔT | ΔP⊠C	s	global	1980–2004	(Koubi et al., 2012)
N	+D⊠C	s	global	1980–2007	(Bergholt & Lujala, 2012)
N	ΔP⊠C	s	Africa	1960–2004	(Buhaug & Theisen, 2012)
N	+T | ΔP⊠C	s	SSA	1981–2002	(Buhaug, 2010)
N	-W⊠C	s, ns	Sahel	1960–2006	(Benjaminsen et al., 2012)
A	W→+C W⊠C	s	global	1880–2001	(Gleditsch et al., 2006)
A	-W→+C +W→+C	s	global	1981–2000	(Gizelis & Wooden, 2010)
A	-L→-C -L→+C	s	global	1950–2000	(Urdal, 2005)
A	ΔP→+C -L | -W⊠C	s	SSA	1981–2002	(Hendrix & Glaser, 2007)
A	-T~+C	s, ns	Central Europe	1500–1900	(Tol & Wagner, 2010)

The column "link" denotes whether there is a significant link between the variables (y) or not (n) or whether the link is ambivalent (a). P = precipitation, T = temperature, D = disaster, W = freshwater, L = land, V = vegetation, C = conflict, → = leads to, + = increase, - = decrease, Δ = change (increase or decrease), ⊠ = no link, ~ = weak link. Example: +P→+C = increase in precipitation leads to an increase in conflict, | = and/or, s = state involved, ns = no state involved, SSA = Sub-Sahara Africa, *projection.

Table 2 Results of key peer reviewed quantitative studies since 2004 on the link between climate change and violent conflict

Based on the mixed evidence, earlier reviews conclude that there is "only limited support for viewing climate change as an important influence on armed conflict" (Gleditsch, 2012, p. 3), but that "environmental changes may, under specific circumstances, increase the risk of violent conflict" (Bernauer et al., 2012, p. 1). We find it important to understand these conditions to move beyond the limitations in current approaches towards more systematic assessments.

As shown in Table 2, quantitative empirical studies are suited to identify significant correlations between climate variables and violent conflict, but they have limited explanatory power with respect to characterizing the causal pathways and their dynamics. In other words, empirical studies may find a correlation but they are hardly able to explain why. Furthermore, quantitative studies predominantly rely on state-based data captured in the UCDP/PRIO Armed Conflict Dataset (Table 2). However, PRIO's definition of conflict limits the studies to conflicts with governmental involvement and an intensity of at least 25 battle deaths per year (Themnér, 2011). Hence low-level events such as protests, riots and inter-group violence are disregarded in such datasets. As climatic changes are expected to mostly affect local (non-government) conflicts, this is in general a significant shortcoming of quantitative studies. Recent projects like the Armed Conflict Location and Events Dataset (ACLED), the Social, Political and Economic Event Database (SPEED) and the Social Conflict in Africa Database (SCAD) attempt to fill the gap by including non-state conflicts, low-level violence, social instability events, and geo-referenced spatio-temporal patterns (see Busby et al., 2012; Nardulli & Leetaru, 2012; Raleigh & Kniveton, 2012; and the supplement in Scheffran et al., 2012b). Due to the huge amount of data it will take time until the upcoming databases cover longer periods and major parts of the world.

In contrast to correlation-orientated quantitative studies, qualitative studies are able to disentangle the complex conflict factors, but they have difficulties to support their claims beyond case-specific data and to establish causality. Both approaches may not be robust against variation of model variables and assumptions, for instance regarding conflict type, involved parties, regional samples, and time periods. They extend past data into a future world with unprecedented rates of temperature rise and its associated consequences. They also lack experience in human and societal responses to such changes. Conflict and cooperation, which

are of core interest for the relationship between climate change and violence, may cancel each other out at the global scale.

3.4 Intermediate Factors and Indirect Pathways

We suggest that a reason for the different findings in the empirical literature on the effects of climate change and violent conflict is the theoretical basis used for quantitative work, which does not sufficiently consider the complexities of the issue. As suggested earlier (Scheffran et al., 2012a; Scheffran et al., 2012b), a complex model of the direct and indirect causal relationships between climate change and conflict is needed. Figure 8 shows connections between the climate system, natural resources, human security, and societal stability. Climate change in itself has various dimensions, with multiple relevant effects on the environment, economics, society, and politics. Most important in this context is the frequency and intensity of extreme weather events, the variability of weather parameters such as temperature and precipitation, and long-term changes in such parameters. These variables may have direct impacts on social systems or indirect implications through other pathways affecting natural resources and human security, which together can lead to ambiguous results.

For each pathway, the consequences of climate change depend on how vulnerable affected natural and social systems are and how sensitive they respond to the stress. At each level, human intervention can influence the systems, e.g. through mitigation and adaptation strategies to reduce risks, strengthen resilience, and improve sustainability. The main focus here is the impact of climate change on conflict, which generally refers to social or political incompatibilities over interests, values, or methods. The definitions of conflict vary with respect to the number of actors, casualties, and the degree of violence. In the context of climate change most studies refer to armed conflict, in which actors use force to achieve their aims.

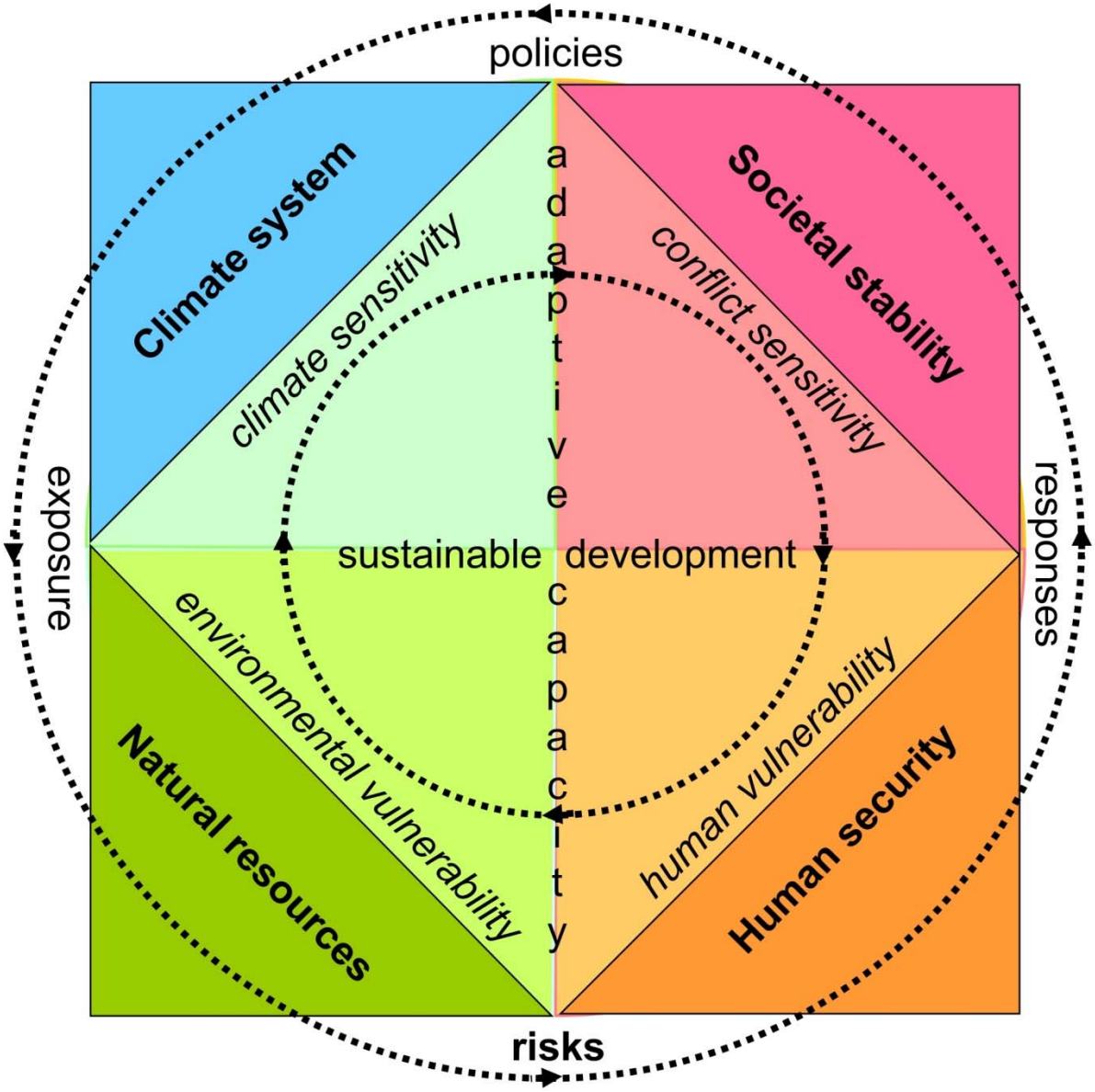

Figure 8 Analytical framework of linkages between the climate system, natural resources, human security, and societal stability
(based on Scheffran et al., 2012c)

There is a wealth of literature on each of the intermediate phenomena. Therefore, we focus only on key messages and references in the subsequent aggregation. Since the 1990s, there has been an extensive scientific debate on how the scarcity of natural resources such as minerals, water, energy, fish, and land affects violence and armed conflict (Bächler, 1999; Homer-Dixon, 1994). While many case studies suggest that environmental degradation and resource scarcity undermine human well-being, the effect on violent conflict "appears to be contingent on a set of intervening economic and political factors that determine adaptation

capacity" (Bernauer et al., 2012, p. 1). Particular attention has been placed on the following intermediate factors (Scheffran & Battaglini, 2011; WBGU, 2008).

3.4.1 Precipitation Changes and Variability

While lack of precipitation and drought may increase resource conflicts in some cases (Opiyo et al., 2012), other assessments support the proposition that the occurrence of conflict, caused by issues on rainfed agriculture or pastoralism, is more likely in rainy than in dry seasons (Table 2). For instance, some studies find that in Kenya the conflict likelihood, in the form of livestock raiding, is greater in years with rainfall abundance than in drought years (Theisen, 2012). People "reconcile their differences and cooperate" (Adano et al., 2012, p. 77) in dry seasons of relative scarcity. Others argue that strong deviations from average precipitation in both directions are related to the onset of violent conflict (Hendrix & Salehyan, 2012; Raleigh & Kniveton, 2012). Generally, political and economic marginalization of ethnic groups is a more significant factor influencing violence than drought (Eriksen & Lind, 2009; Theisen, 2012). Other studies (e.g. Koubi et al., 2012) do not directly test for a relationship between climate variability and conflict but rather proceed in two stages: they first estimate the effect of temperature on economic growth and then assess the relationship between growth and conflict.

3.4.2 Freshwater Resources and Scarcity

Systematic empirical assessments demonstrate that international river systems are more associated with low-level conflicts and diplomatic tensions than with full-scale wars (e.g. Bernauer & Siegfried, 2012; Brochmann & Hensel, 2009). According to the Transboundary Freshwater Dispute Database the evidence for war between countries over water is low. The number of international water agreements has been rising over the past decades, which indicates growing cooperation (de Stefano et al., 2012; Wolf, 2007).

3.4.3 Land and Food

Climate change is likely to contribute to food insecurity in parts of the world (Gahukar, 2009), while food insecurity can contribute to violence (Messer, 2009). This has been highlighted by the "food riots" that occurred in several countries between 2007 and 2011, which correlated with rising food prices (Bush, 2010; Sternberg, 2012). So far, there is little explicit evidence of climate change as a contributing factor in this context (Johnstone & Mazo, 2011). Also, the role of climate change in conflicts among pastoral and farming communities over land and pasture in Sub-Sahara Africa is ambivalent (Adano et al., 2012; Benjaminsen et al., 2012). One study indicates that rainfall-related economic shocks increase land invasions and hence the potential for conflict, as shown for regions with highly unequal land distribution in Brazil (Hidalgo et al., 2010).

3.4.4 Weather Extremes

In addition to the study on the ENSO phenomenon (Hsiang et al., 2011), additional publications have found relevant evidence of links between extreme weather events and armed conflict. This includes studies of natural disasters (Nel & Righarts, 2008), which arguably have similar effects as those predicted by extreme weather events such as floods and storms. However, other assessments (Slettebak, 2012) do not support this result and find no increased likelihood of civil armed conflict after natural disasters. Among those, Slettebak (2012) argues that in crisis situations cooperation prevails over conflict. Future studies using broader sets of data including low-level violence should take into account both conflict and cooperation as consequences of weather-related extreme events.

3.4.5 Environmental Migration

There is a wide range of estimates on the number of future migrants who are driven by environmental and climatic changes (Jakobeit & Methmann, 2012). Empirical findings reach no consensus whether environmental migration can act as a precursor for violence (Barnett & Adger, 2007; Reuveny, 2007). Recent studies rather suggest to treat migration as an important adaptation measure to climate change (Black et al., 2011), which could strengthen the resilience of affected communities, e.g. through remittances (Scheffran et al., 2012d).

3.5 Geographical Distribution of Vulnerabilities

A large body of literature suggests that the impact of climate change on human beings and societies is shaped by the vulnerabilities specific to each region (e.g. Füssel, 2010; Parry et al., 2007; Samson et al., 2011). The vulnerability to climate impacts can be broken down into three factors: i) exposure to climate change, ii) sensitivity to climate change, and iii) adaptive capacity (Parry et al., 2007). While exposure can be considered to be independent from conflict, the other two cannot, suggesting that the climate-conflict link is not a one-way road.

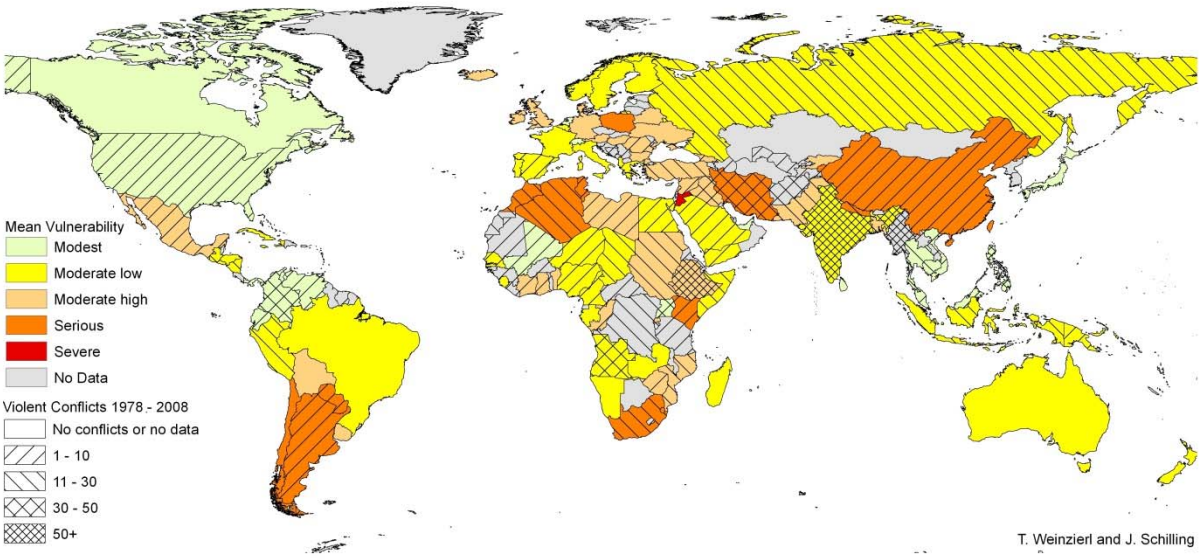

Figure 9 Mean vulnerability to future climate change and the number of recent armed conflicts. The vulnerability shown is the mean between the vulnerability index for climate sensitivities of 1.5°C and 5.5°C, both calculated for the IPCC A2 emission scenario until 2050 (Yohe et al., 2006b). The vulnerability index is a measure of climate change exposure, sensitivity, and adaptive capacity (for details see Yohe et al., 2006a; Yohe et al., 2006b). The conflict data are from UCDP/PRIO Armed Conflict Dataset v.4-2011 (PRIO, 2011)

In Figure 9 we identify countries that have recently been sensitive to violent conflict (using the number of armed conflicts in the past three decades) and countries that are vulnerable to future climate change (using an established indicator for climate vulnerability). This provides a geographical representation of countries that are facing the double exposure to both climate

change and violent conflict, only one of these phenomena, or none of them. Several questions arise: Will regions that are prone to violent conflict also become more affected by climate change? Could increased climate impacts undermine adaptive capacity and add to conflict? How do climate vulnerability and violent conflict interact in "hot spots" that suffer from this double exposure?

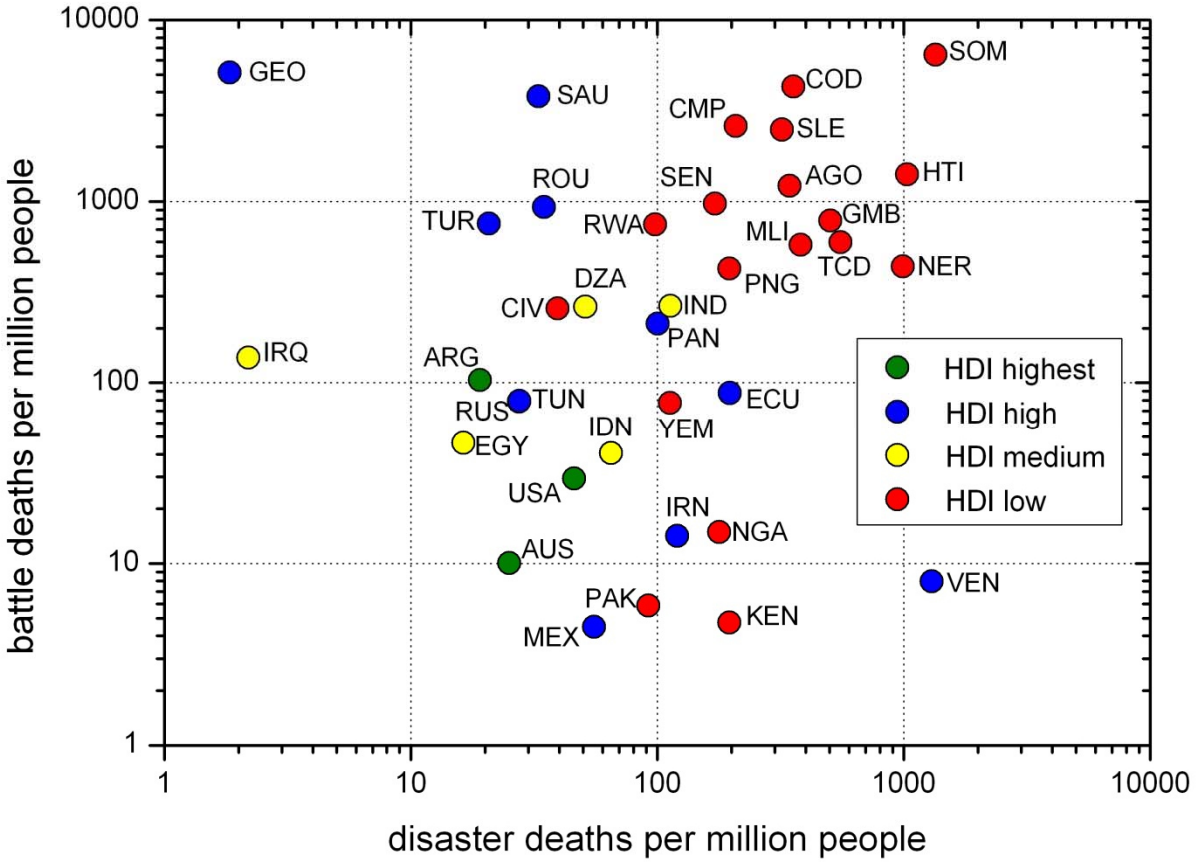

Figure 10 Battle deaths vs. disaster deaths in countries that have experienced casualties in both categories between 1978 and 2008
(UCDP/PRIO and EM-DAT for the time period 1978-2008). The disasters considered are drought, epidemic, extreme temperature, flood, insect infestation, wet mass movement, storm, and wildfire. The categorization of development is based on the 2011 Human Development Index

Country codes: AGO Angola, ARG Argentina, AUS Australia, CIV Cote d'Ivoire, CMR Cameroon, COD Congo, DZA Algeria, ECU Ecuador, EGY Egypt, GEO Georgia, GMB Gambia, HTI Haiti, IDN Indonesia, IND India, IRN Iran, IRQ Iraq, KEN Kenya, MEX Mexico, MLI Mali, NER Niger, NGA Nigeria, PAK Pakistan, PAN Panama, PNG Papua New Guinea, ROU Romania, RUS Russia, RWA Rwanda, SAU Saudi Arabia, SEN Senegal, SLE Sierra Leone, SOM Somalia, TCD Chad, TUN Tunisia, TUR Turkey, USA United States of America, VEN Venezuela, YEM Yemen

Although definite answers cannot be given yet, it is worthwhile to examine the factors that shape this interaction. A comparison of the number of deaths from natural disasters and battle-related deaths in the past (scaled for comparability using the population in each country) reveals that both are highest in countries with a low human development index (see Figure 10). Many of these countries are home to the world's poorest people who already experience increased threats to their lives and health that undermine human development. If climate change adds to these risks and vulnerabilities, it can increase humanitarian crises and aggravate existing conflicts without directly causing them.

3.6 Governmental Responses, Governance, and Institutional Frameworks

Human development and adaptive capacity are fundamental ingredients to contain the double exposure of conflict and climate risks. Their interaction is related to the concept of human security, which refers to the reduction and elimination of vital anthropogenic threats to the life and health of individuals and communities (Ogata & Sen, 2003). The potential effects of climate change on human security are decisively influenced by the responses of local, national, and international actors, which may both reduce or increase the likelihood of climate-induced violence.

While global temperature has been rising in the past decades, the number of armed conflicts has declined since the end of the Cold War (Figure 11). The growing wealth per capita and the spread of democracies increase the chance of an expansion of adaptive capacity in many parts of the world, which counters climate exposure and sensitivity. Until the global financial crisis of 2008, humanitarian aid and development assistance have increased (OECD, 2012). In many parts of the world this contributed to important improvements in the living conditions of people who are potentially most vulnerable to the effects of climate change. With the global financial crisis, however, the situation has become more severe again.

International efforts to prevent and manage conflicts have been strengthened, which has considerably reduced the number of armed conflicts and battle deaths (Figure 11). In recent years, however, this trend seems to have come to a standstill, and it is not clear how conflict

prevention and management will evolve in the future. A particular problem is the capacity of conflict management institutions from local to global levels to deal with sub-national conflicts and multiple crises simultaneously. Effective institutional frameworks, governance mechanisms, and democratization are often seen as an important precondition for peaceful management of conflict. Democracies have rarely fought each other in the past, and democratic states also have seen fewer incidences of civil war in the past decades (Gleditsch et al., 2009). The number of democratic states has generally grown in waves over the past half century, which concurred with a decline in armed conflict. More recently, low-level violence and the number of fragile states with weak institutions have slowly increased (Marshall & Cole, 2011; Stewart & Brown, 2010). Still, there is a risk that institutions could be overwhelmed by climate change related crises (WBGU, 2008).

While the United States and the United Kingdom consider climate change as a major future problem for national and global security, other states such as Russia and China have paid minor attention to this issue so far. The divergent views have been expressed in the two controversial debates in the UN Security Council in 2007 (initiated by the UK) and in 2011 (initiated by Germany). Main areas of military concern are interventions in fragile states, the securing of borders, and access to resources, e.g. in the Mediterranean or in the Arctic region (see Brauch, 2010; Brzoska, 2012). The debate on the securitization of climate change has enhanced the focus on its risks but this discourse also entails the danger of the militarization of climate change with unintended consequences. For instance, it may instigate policy makers to choose violent means when facing crisis situations with links to climate change, which raises the likelihood of armed conflict. Furthermore, it may undermine the conditions for cooperation and reduce the financial means available for mitigation and adaptation measures. Some of these responses to climate change could become causes of conflict themselves (Webersik, 2010) such as the competition of bioenergy and food production for land, or the potential quarrel between states over climate engineering. Some of the technical fixes to reduce climate change or its effects could be introduced in unilateral action by some states at the expense of other states. In general, it is important to consider the implications of mitigation and adaptation measures for the interests of the many groups of stakeholders involved and to aim at avoiding the creation or further aggravation of conflicts.

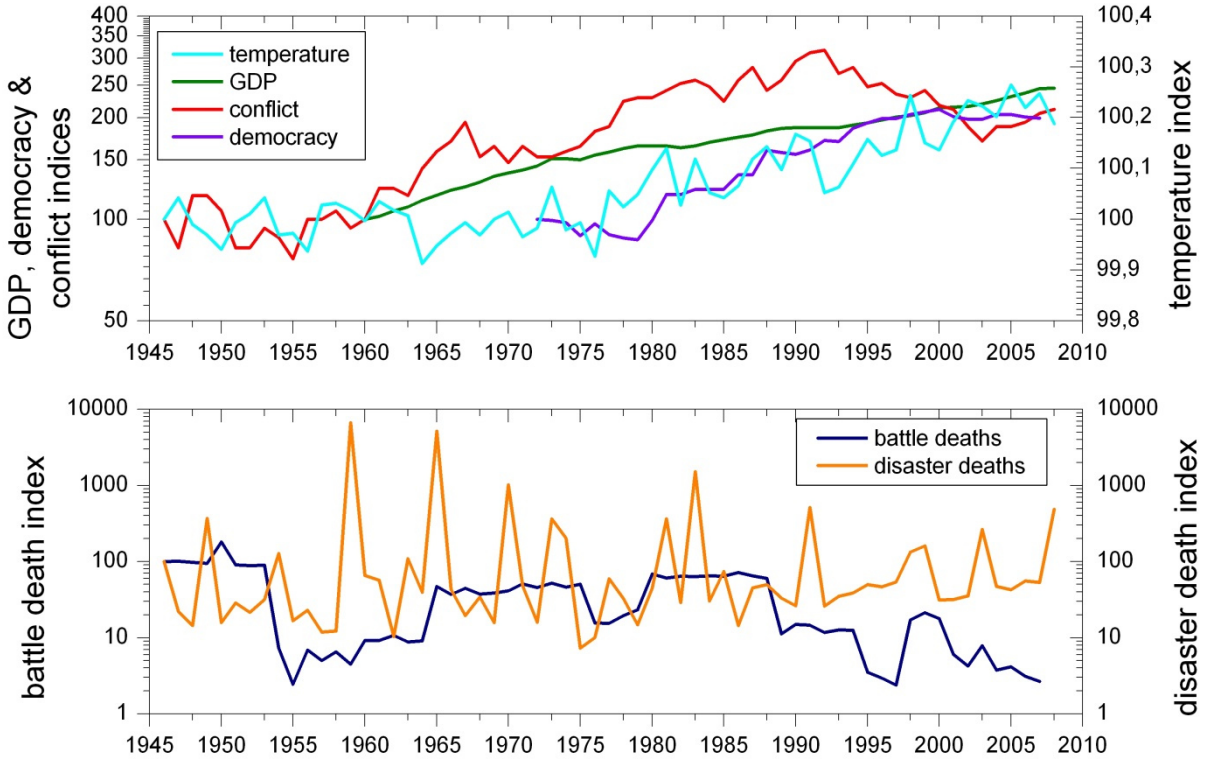

Figure 11 Development of indices of global sea surface temperature (top right scale, based on Kelvin), per capita gross domestic product, number of violent conflicts, democratic countries (top left scale), and casualties from battle and disasters (bottom logarithmic scales)
(NOAA, World Bank Online Database, UDCP/PRIO, Freedom House Index, Correlates of War Interstate Wars, EM-DAT). For all indices 100% is set for a reference year.

3.7 Conclusions and Future Research Challenges

A significant part of the current literature supports the argument that climate change has an influence on violent conflict in at least some regions of the world. However, while quantitative studies tend to provide evidence for a link between climate change and violent conflict over longer historical periods, results for recent periods are more ambiguous. Other trends and events may have had a larger influence on violent conflict than climate change. Two examples from the recent past are the end of the Cold War and the increase in international activity to stop armed conflict in many parts of the world. However, without strong mitigation efforts future climate change may by far exceed levels that have been reached in human history. If major 'tipping points' of societal stability are reached, climate change may become a major driver of armed conflict in the future.

At present, such predictions are based on presumptions and not on evidence. Assessments of the links between climate change and violent conflict are still unclear about many important elements. A relevant constraint is the lack of understanding of the escalation from non-violent to violent conflict. Further important limitations of current research are inadequate data (e.g. on rainfall), insufficient indicators (e.g. of drought or conflict independent of violence), and the lack of comparability and generalization for different regional contexts and intermediate pathways. More micro level data on violent conflict would help to understand feedback effects between climate change and conflict at subnational levels (Nardulli & Leetaru, 2012). In addition, data on social and political processes that can lead to violence are needed. Causality is hard to measure as numerous variables, complex interactions, and long chains are involved.

Future analysis may more specifically look at the various pathways of interaction between the climate system, natural resources, human security, and societal stability that have been indicated in Figure 8. Besides the direct effects of climate change on society, e.g. through extreme weather events, the more indirect causal chains need further investigation. This includes large-scale impacts on ecosystems, food and water supply, health problems, income shocks, human migration, and ultimately violent conflict. It is key to improve the understanding of vulnerability and sensitivity of the affected systems with regard to a changing climate. It is important to determine whether these systems are able to maintain resilience, and how the factors and processes shape adaptive capacities, strategies, and their successful implementation. A related question is how these systems respond and interact if the climate stress exceeds critical thresholds of adaptive capacity. Will such development trigger tipping elements, cascading events, and ultimately violent conflict, or will it rather lead to coordinated responses and cooperation to jointly address the future global challenges, e.g. by a transformation towards low-carbon societies?

As explained before, it is necessary to use a more complex, comprehensive approach to study the links between climate change and violent conflict. The various linkages indicated in Figure 8 open up a multitude of possibilities of how climate change may be linked, via intermediate factors, to violent conflict – or not, if the pathways do not materialize or are moderated by other factors shaping violent conflict. A lot of research has been done and is on the way to investigate those linkages. However, it needs to be better related and integrated

into a framework such as the one suggested here. The prime objective of the framework is to combine quantitative empirical analyses, qualitative case studies, and modeling of the complex human-environment interactions. To further address the ambiguities, uncertainties, and limitations of current quantitative research, data are needed on low-level conflicts and their geographical and temporal distribution. Models could build on a rich set of modeling tools from complexity science, multi-agent systems, social network analysis, and conflict assessment that extend previous data and experiences into future scenarios, covering different social, economic, and political contexts. Developing an integrative framework would help to overcome the current deficits in research and identify under which conditions climate change would lead to violent conflict or its prevention.

4 Global climate policy reinforces local social path dependent structures: More conflict in the world?

Jasmin Kominek

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Keywords

climate change, violence prevention, path dependency

4.1 Introduction

Climate change is a global phenomenon and there are an increasing number of attempts to discuss and solve related problems at a global level. This increasing emphasis on, and empowerment of, global institutions can have side effects on local power structures. The following analyses indicate that increasing global institutionalization can lead to an intensification of local conflicts around the world. This conclusion follows from an application and extension of the concept of path dependency. Examples are given of how local self-reinforcing structures can be used in a positive way to smoothly trigger an increase in mitigation and adaptation capacities.

Decisions on climate policy at the global level affect the options for policies at sub-global levels. If, for instance, it was decided at the *global* level that all countries around the world should build more nuclear power plants, then *national*, *regional*, and *local* social structures would be affected as well. On the one hand, large building companies, energy groups, and related political parties might use the legitimization of such policy to push their own interests and to increase their revenues. On the other hand, opposing groups such as green parties, village groups potentially affected by radioactivity in the vicinity of a newly-built nuclear

power plant, and civil society groups that worry about possible contamination of the environment and about increasing security risks would probably join large demonstrations, and organize actions to blockade construction work. The actions of one of the coalitions in this confrontation can cause the opposing groups to tighten their positions and strengthen their power structures, and vice versa. In this scenario, a recursive self-reinforcing phenomenon is triggered and enhanced by actions at the global level. The scenario described demonstrates that decisions reached at the global level can influence local structures. The importance of the global level can also be extended to political dynamics prior to decisions, e.g. when these provide legitimacy for the positions of local agents.

The link between the global and the local level can be described using an extended path dependency theory. This approach is useful for analyzing how dynamics are triggered and increased within existing social structures in a self-reinforcing way. Independently of content, certain structural dynamics can be described that shape people's behavior. These are also relevant for considering the side effects of policies responsible for climate change, as well as policies for its prevention, mitigation, and adaptation.

Firstly, and based on the different steps in a problem-solving process, a formal scheme is presented. This scheme distinguishes between the overall problem-solving process (4.2), situational analysis (4.3), modeling and evolving strategies (4.4), and situational intervention (4.5). Using this structure, in each section each step is explained in greater detail and the theoretical background is presented, expanded, and developed. This leads to the concluding hypothesis that global climate policy can lead to an intensification of local conflicts around the world (4.6).

As political negotiators are likely to be affected by path dependency, this phenomenon is defined and its theoretical background explained in the section considering the overall problem-solving process (4.2). In the following section, the theory is expanded to draw conclusions from the macro-level phenomenon for micro-level agents, and to assess possible changes in individual decision-making resulting from path dependency. Next, a formal multi-agent model is presented to show that with increasing effects of path dependency, the variance of the actions by people affected tends to be reduced. Furthermore, people increasingly see

only the narrowing set of possibilities as the basis for their actions. Finally, situational intervention and the implementation of chosen strategies are discussed.

Examples are given of how the self-reinforcing character of path dependent processes can be deliberately used to trigger dynamic action processes that are directed at mitigation and/or adaptation. These processes are chances to positively apply knowledge on social dynamics by enhancing non-conflicting measures. Meanwhile, the perceived or actual narrowing of options through political processes at the global level in turn generally exacerbates national and local conflicts, consequently leading to their amplification. A conclusion briefly summarizes the insights gained from the path dependency perspective and underlines the necessity to include it in considerations of global climate-change-related policy.

Path dependency is a concept used in many areas of social analysis. It can be expanded to explain micro-level behavior as well as the dynamics of the interaction of agents on different levels (Kominek, 2009). This chapter aims to apply this approach to the question of climate-change-related actions. The particular question addressed is the effect of path dependency on conflict. It is argued here that there are structural dynamics, described by path dependency theory, which can lead to an intensification of already existing national and local conflicts triggered by global climate politics. This provides the theoretical underpinning of the scenario used in the opening section of this chapter (nuclear power plants).

The importance of path dependency theory is often questioned (Alexander, 2001; Liebowitz & Margolis, 1995). It can be asserted, for instance, that revolutions can disrupt macro-level structures and politicians and societies may suddenly act in completely different ways. However, contrary to this it can be argued that basic behavioral routines can survive a revolution and can actually reinforce structures in an even more powerful way (chapter 7 of this thesis). Analysis of how path dependency affects a single agent at the micro level helps us understand such findings. These considerations are presented in the section on situational analysis and interpretation (4.3, 4.6).

4.2 The Overall Problem-solving Process

Climate-change-induced degradation of freshwater resources, climate-change-induced decline in food production, climate-change-induced increase in storm and flood disasters, and environmentally induced migration are the four "typical causal linkages at the interface of environment and society, whose dynamic can lead to social destabilization and, in the end, to violence" (WBGU, 2008, pp. 2-3). In the light of these facts, a high willingness to prevent climate change and mitigate negative effects on society and the environment can be assumed.

However, a person living in a rented apartment cannot easily exchange wooden window frames or change the heating system to reduce carbon emissions. It is hard to estimate, when buying an apple or a T-shirt, how much its particular storage, production, or transport costs in carbon emissions or water. An agent could try to reduce her power usage, but embedded in social networks as she is, the necessity of staying available requires a certain minimum use of electronic devices in the modern world. Thus, even though we have discovered that climate change occurs and we may have developed preferences about how to reduce carbon emissions or emissions from soot aerosols or how to conserve fresh water, these preferences are to some extent kept from directly influencing our actions by the institutions or social structures that surround each one of us. This behavior can be described as a path-dependent behavior in contrast to a primarily rational one, which would mean reflecting on and optimizing our preferences and acting accordingly. If even the everyday behavior of any single agent needs to be described in terms of path dependency, every agent involved in negotiations about climate change policy, every agent who is affected by climate-change-induced disasters, and those who try to intervene in situations, are likely to be to some extent influenced by the surrounding structures instead of being driven by rational preferences only. Therefore, the problem-solving process itself needs to be considered in detail, so as to gain an impression of the unintended structural side effects, and to increase the chance of avoiding conflict resulting from effects directly related to climate change.

4.2.1 The Formal Scheme of a Problem-solving Process

To provide an analysis of the underlying mechanisms, the overall problem-solving process can be divided into a first part of analyzing and interpreting the situation, a second part

consisting of modeling and the deduction of strategies, perhaps by use of simulations, and a final part consisting of intervention in real situations through implementation of the strategy (Figure 12).

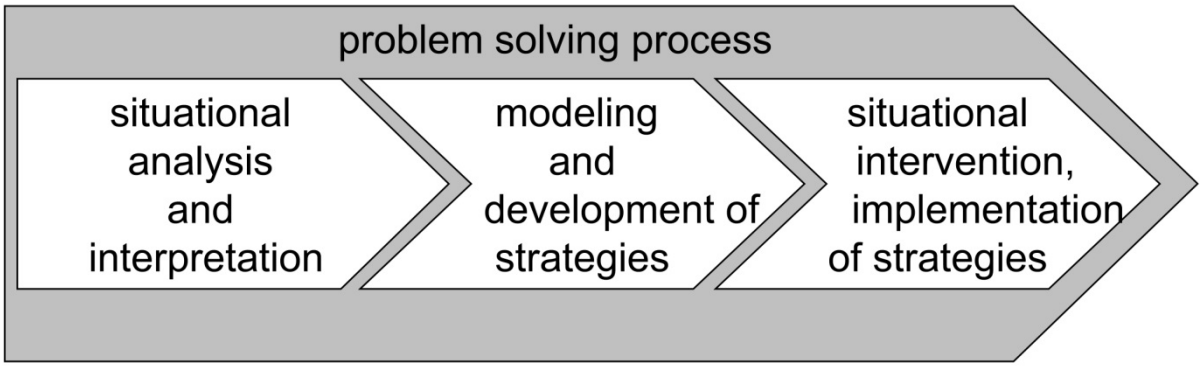

Figure 12 The formal scheme of a problem-solving process. A problem-solving process consists of four parts: the overall problem-solving process, in which political negotiations can occur, a part consisting of analyses and interpretation, followed by modeling and simulations. The final part is the implementation.

In each of these steps agents can be assumed to be present, e.g. debating on the overall problem-solving process, trying to decide politically who is most competent, who most affected, who is responsible, and who needs to pay how much and when. In the situational analysis it is important to make assumptions about how the observed agents reach their decisions in order to be able to interpret their behavior and the present state of social dynamics they are in. Who decides rationally about economic goals? In which situations might people affected by climate change panic and simply fight for survival? And in which situations does survival depend on decisions of institutionalized power structures instead of individual agents' other preferences?

The same behavioral decisions are also important in modeling and in the resulting strategies, where the political agents who negotiate strategies are influenced by micro-politics as well as climate-change-induced issues. In the final analysis, the type of situational intervention is decided upon by political agents, and these agents are present in executing the strategies in real situations in society, where, for example, agents affected by climate-change-induced

issues live and act. If all these agents are shaped and affected in their behavior by the social structure surrounding each individual, what is the result?

4.2.2 Path Dependency

If we consider the path of producing high emissions and another theoretical path of producing only low emissions, the combination of mechanisms that make us stick to the high emission path and prevent us from simply switching to the other (preferred) one can be described in terms of path dependency.

Path dependency is a phenomenon that implies that present decisions depend on former ones or on historical events. From a macro perspective, these sequences of decisions and the resulting actions are lined up, forming a path. There are different areas of society, technology, and science in which path dependency can be observed. Some authors argue that, in the case of technology, the selection of some technologies rather than others is made through efficiency criteria and is the result of perfect market selection mechanisms; in other fields such as politics there is less debate that path dependency occurs, and it is likely that paths will be manifested that inhibit correcting mechanisms and thus lower the chances for different actions to be taken in the future (Liebowitz & Margolis, 1995).

In the case of the high or low emission paths in the previous example, bureaucracy and institutionalized processes can be made responsible for preventing the tenant of the apartment from switching to a lower emission path. In the case of consumption, opacity prevents markets from selecting sustainable products to succeed. And in the social network example, dependency on instant information, frequent communication, and global social networks as manifested habits and reinforcing social structures prevents agents from switching to low emission paths. So that existing theory can be used from the outset and expanded later, the current state of research into path dependency theory will be outlined first.

4.2.3 The QWERTY-Keyboard: An Example of the Phenomenon of Path Dependency

The notation of path dependency used in a sociological context was originally coined in economics (e.g. Arthur, 1989, 1994; Beyer, 2005; David, 1985, 2001, 2007). In a narrow sense, a process is considered to be path-dependent if it is a self-reinforcing process with the potential for a lock-in (e.g. Sydow et al., 2005, 2009). A broader understanding allows the use of path dependency more as 'history matters', which means that past events influence present and future actions (going back to Arthur, 1989; David, 1985). The most popular example for understanding and describing path dependency is the case of the QWERTY-keyboard. Present (English language) computer keyboards (still) usually have the keys QWERTYUIOP in the topmost row of letters, which is why they are called QWERTY-keyboards. The question may be asked as to why this appears to be resilient against change and why the keys were placed on a QWERTY-keyboard in the first place.

The key placement in exactly the layout we know today resulted from different optimization processes to prevent former type bars from clashing and jamming. But the final key placing of the letters in the topmost row occurred because the first production line of typewriters was called TYPE WRITER and the company wanted their salesmen to be able to type the brand name quickly in product presentations (David, 1985). So they ensured that all the letters in TYPE WRITER could be found in the topmost row. And even though those reasons have long since disappeared, today's keyboards look just the same although there are different alternatives available for improving keyboard ergonomics or completely changing the method of entering text in an electronic device. The QWERTY-keyboard still is widespread, used, bought, and applied even on smartphones that do not have keys at all.

> "The agents engaged in production and purchase decisions in today's keyboard market are not the prisoners of custom, conspiracy, or state control. But while they are, as we now say, perfectly 'free to choose', their behavior, nevertheless, is held fast in the grip of events long forgotten and shaped by circumstances in which neither they nor their interests figured (David, 1985, p. 333)."

Applying this summarized description to the case of high or low emission paths, you get statements such as the following: while apartment leasers, consumers of apples and T-shirts, and members of modern global society involved in social networks are *free to choose*, their

behavior is shaped by former events manifested in the structures surrounding them that were shaped by former circumstances where carbon emissions and climate change did not matter.

4.2.4 Debate on the Concept of Path Dependency

Pierson (2000) summarizes the characteristics of path-dependent processes (relating to Arthur, 1994, pp. 112-113) with the terms unpredictability, inflexibility, non-ergodicity, and potential path inefficiency. At the beginning of a path its final state cannot be predicted, in the lock-in it is difficult to change paths, small events at the beginning of the path may have large effects through positive feedback mechanisms, and "in the long-run, the outcome that becomes locked in may generate lower pay-offs than a foregone alternative would have." (Pierson, 2000, p. 253). While it seems difficult to actually use a concept based on processes that are characterized as unpredictable, it is used in various ways.

In organizational sciences; Sydow, Schreyögg, and Koch use the narrower notation of path dependent processes, which characterizes them as self-reinforcing processes with the potential for a lock-in: they suggest a 3-phase model to describe a path dependent process, where in phase 1 contingency is present, in phase 2 self-reinforcing mechanisms more and more restrict actions until the lock-in occurs; and in phase 3 action changes at most incrementally (Sydow et al., 2005, 2009). Relating them to various fields of science, Beyer (2005) lists seven mechanisms that can be characterized as containing the logic of assuring continuity. And Page (2006) analyzes different clusterings of mechanisms that affect whether processes become path dependent, and assesses characterizations of path-dependent processes in mathematical modeling. Using stochastic processes, Page expands Arthur's models.

Pierson (2000) states that every institution in political science is path-dependent. In contrast, Alexander (2001) argues that politicians do not make decisions in an entirely rational way, so the economic definition of path dependency is not applicable without restrictions. On the other hand, Mahoney (2000) transfers the context of path dependency to the social sciences and points out that the phenomenon cannot be sufficiently explained using economic approaches such as utility theory, because trying to explain inefficiency with a concept that does not allow any other result than efficiency is a paradox.

North (1990, 2006) describes institutions as locked-in (and thus in terms of path dependency) when they can be only incrementally changed by organizations. At a theory-combining level, processes of institutionalization can be described as self-reinforcing processes and thus in the terminology of path dependency (chapter 7 of this thesis, referring to Giddens (1984) and Berger and Luckmann (1979)). Liebowitz and Margolis (1995) present a characterization of path dependency phenomena consisting of three categories differentiated by the degree of inefficiency they produce, but they still argue whether the QWERTY-keyboard is actually an example of inefficiency, and thus market failure. Because, if the QWERTY-keyboard was the best solution for agents' local needs, the market would prove it was working well in selecting the QWERTY-keyboard as dominant technology.

What all these approaches have in common is that they more or less describe path dependency by focusing on the phenomenon: they try to discover paths on which path dependency acts in empiricism, characterizing path dependency using the attributes *unpredictability*, *inflexibility*, *non-ergodicity* and *potential inefficiency*. They also distinguish paths in phases, cluster mechanisms around them, compare and cluster path dependent phenomena and try to describe them with mathematical models. But as Garud and Karnøe (2001) point out, although agents are central to the process of path dependency, a theory of agency is still not available to characterize them.

Thus, if path dependency shapes social structure and the actions of agents through institutions, what would happen if a climate-change-induced disaster destroyed institutional infrastructure or if a revolution broke the paths and changed the contents? And what if agents just deliberately acted differently?

Even if social structures were suddenly blockaded or vanished at the institutional (macro) level, the previous impacts that path dependency had had on the decision-making processes of each affected agent (at the micro level, as deduced in the following sections) would still shape their behavior. That way, new path dependent processes and structures are likely to be created (Kominek, 2009) through the back door, which would influence the involved agent's action even more intensely (due to primary-like socialization, see chapter 7 of this thesis). Of course,

as long as agents do not act entirely path-dependently, they should be able to deliberately act differently. Still, from the mere fact that paths actually affect agents in their decision-making and shape their behavior to a degree that may be assumed, some predictions can be made.

4.3 Situational Analysis and Interpretation

As just discussed in detail, one characteristic description of how path dependency affects agents' behavior is that their decisions and actions are shaped by past events which had no relevance to their present preferences (David, 1985, p. 333). While for example politicians debated whether it was useful to rebuild New Orleans after Hurricane Katrina in a more secure way to prevent future disasters, to enrich the lifestyle of the inhabitants of the city, or to design the new houses in a more appropriate way, local residents acted in an obvious way: "The actual decisions and rebuilding undertaken to date, the so-called 'facts on the ground', clearly demonstrate the rush by the residents themselves to rebuild the familiar" (Kates et al., 2006, p. 14659). Trajectories of recovery can be identified that predict that a recovery generally follows the pre-disaster trajectory, with the disaster even accelerating previous trends (Kates et al., 2006, p. 14658).

When you look at the current situation, interpret the agents' actions and assume that path dependency is affecting their behavior, the present goals of these actors cannot necessarily be deduced, because instead of striving to reach their goals, they may more or less simply stick to paths. Just the same, if asked they may answer that they actually feel free to choose what they want to do and they are happy with what they do all the time anyway. And they perhaps could even name a worse alternative to justify their action. One example could be that imported food is preferable to local food because local storage and refrigeration over time would produce more carbon emissions than an optimized transportation system from abroad. Or the other way round, local food could produce fewer emissions because transport distances are shorter, even though it might happen that each agent drives to the nearest farm by car. Other agents may not be happy with what they do and perhaps just do not feel free to choose differently, as they do not see any viable alternative for them. A suitable example for this is the wooden window frames or the heating system, which a tenant of an apartment cannot decide upon by herself.

Furthermore, if asked to state their individual goals, e.g. to reduce carbon emission, it can be difficult to deduce from the agents' answers whether the goals mentioned are mere justification or have a real basis and are evidence for rational choice. Some agents might even answer that they do not have any special preferences or goals or that they do not know them. This may be true in some cases because when choosing between perhaps only one or two obvious alternatives it is not necessary to have a large variety of goals in order to pick one particular path. Therefore, more interesting and relevant than analyzing the agents' goals and motivations is analyzing how agents' behavior is influenced by surrounding paths.

4.3.1 Ideal Type Path-Dependent[10]

So, what exactly happens if an agent is affected by path dependency – what does it mean for an agent to decide path-dependently? Because path dependency cannot be entirely explained by utility theory alone (Mahoney, 2000), it can be concluded that a path-dependent decision cannot be described as substantially rational (Simon, 1976) or as an 'ideal type rational-calculative' one (Esser, 2005). This is true even though actions can usually be rationalized, which means that they can be explained ex post facto in terms of a rational decision as to why for example one T-shirt is better than another, while sustainability arguments just cannot be monetized or are weighted with a coefficient of zero and consequently do not show up in the final result of the observable action. So an agent's rationality is bounded (Simon, 1976) by the individual horizon and the surrounding environment evokes decision frames that shape the resulting action.

Esser (2005) describes a model of frame selection as an expansion of classical rational choice theory. In this chapter, a similar argument is presented using fewer assumptions. Nonetheless, these are sufficient for subsequent analyses, resulting in an 'ideal type path-dependent' that can be used as the basis for a multi-agent agent-based model that describes agents' behavior when optimizing emission reduction or simulates local agents' behavior with regard to their reaction to climate-change-induced events.

[10] The term *ideal type path-dependent* is deduced from the terms ideal type *rational-calculative* and ideal type *automatic-spontaneous* (Esser, 2005; cf. Kominek, 2009).

4.3.2 The New Model Frame

If a path can be monitored at the macro level, there must be some similarity in the observed actions that makes them appear as if they were lined up forming a path. This similarity implies that some part of actions that are taken stays the same over time, which means it can be described as some form of constancy or routine. So, if one were living in a rented apartment, one routine could be to simply use the existing heating system instead of arguing each day about changing the heating system, before warming the bathroom in the morning.

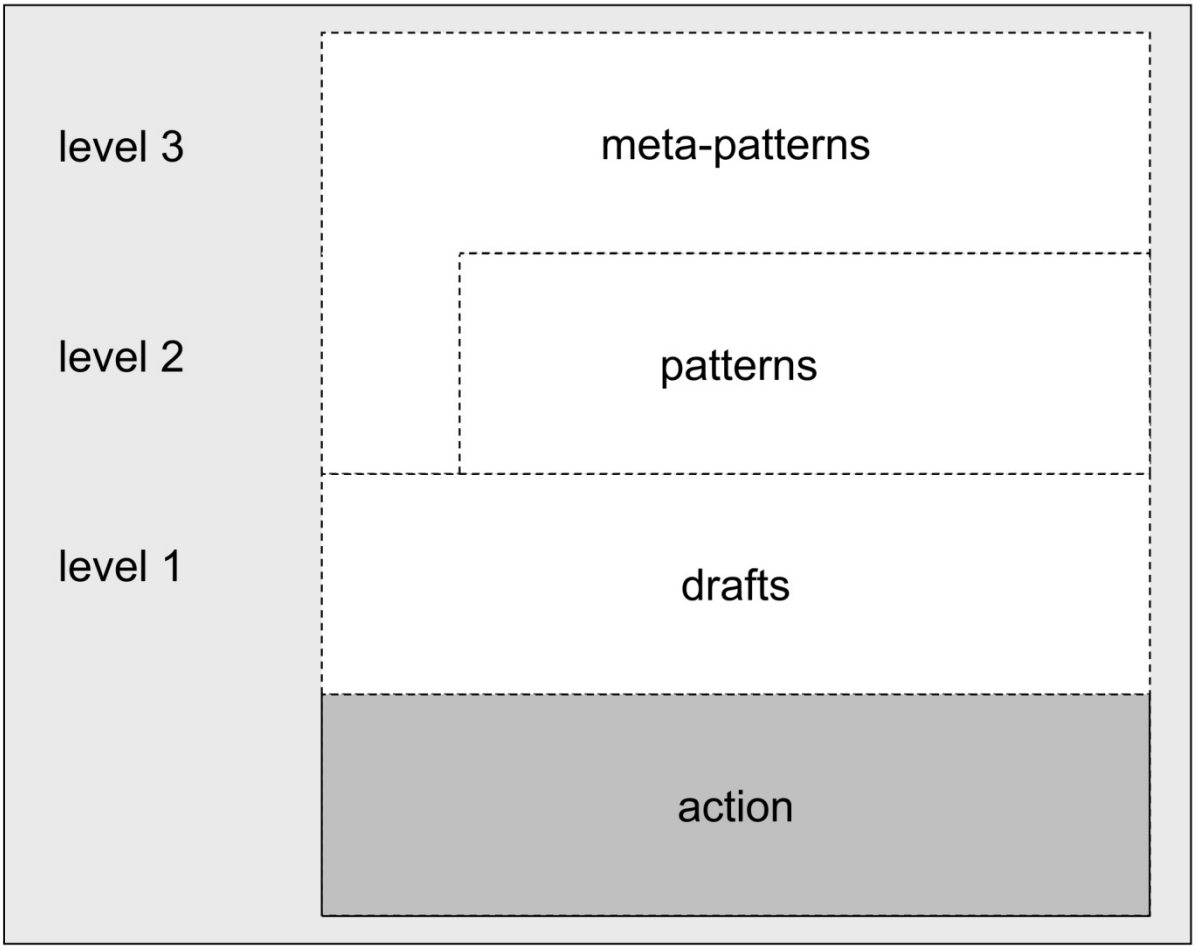

Figure 13 Model framework of the new action model.
The decision process can be separated into different levels of consciousness that can be applied. The process is initiated on level 1. Levels 2 and 3 are only used if necessary. The dashed lines indicate that no further chronology is fixed, but contents of all three levels could be combined (Kominek, 2009).

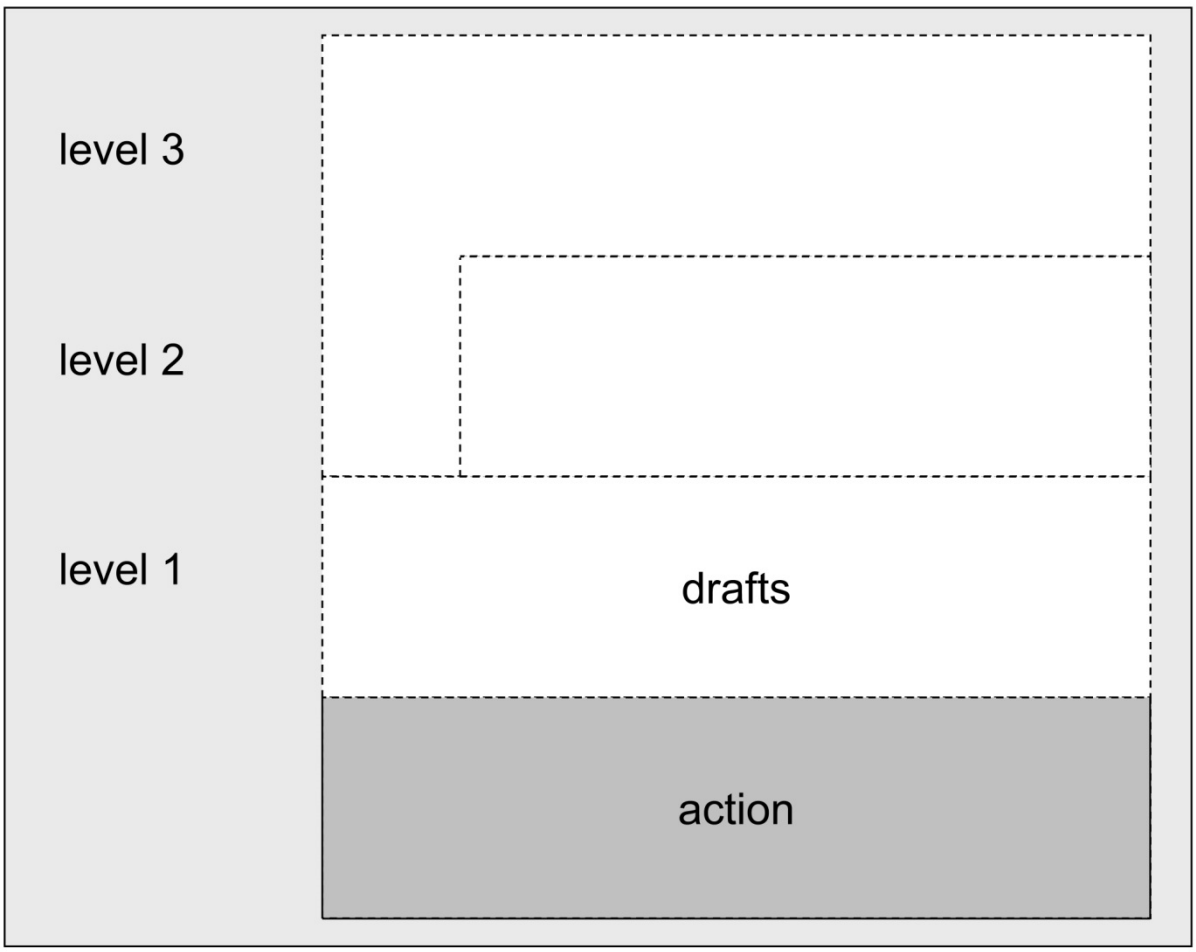

Figure 14 Decision framework of an ideal type 'automatic-spontaneous' agent.
Only the level of drafts is necessary for action. Prior to action, one particular action draft must be selected to be executed (Kominek, 2009).

In the following model, this least-effort principle is not implemented as a deliberate rational choice, which would also be possible. It is even applicable on a more basic psychological level, such as in social psychology when scientists describe how the brain works. In social psychology (e.g. Chaiken & Trope, 1999) it is usually assumed that a real executed action is preceded by an activated cognitive action draft. Therefore, level 1, the level of drafts in the model frame (Figure 13), is the level of action drafts, where exactly one draft needs to be chosen and activated prior to the real action. To describe an automatic-spontaneous action with this model frame, the lower two rows would be sufficient (Figure 14). The action decision-making process is therefore initiated on level 1, the level of action drafts. If more

than one draft can be chosen that can be considered to be comparably practicable, or if no single draft can be chosen as perfectly matching on this level, a further decision process is necessary to solve this inner conflict (cf. Chaiken & Trope, 1999). Consequently, one model assumption is that only when an automatic-spontaneous decision is deemed impossible or infeasible are other decision criteria added to the decision process and thus a decision process different from an *ideal type automatic-spontaneous* is started.

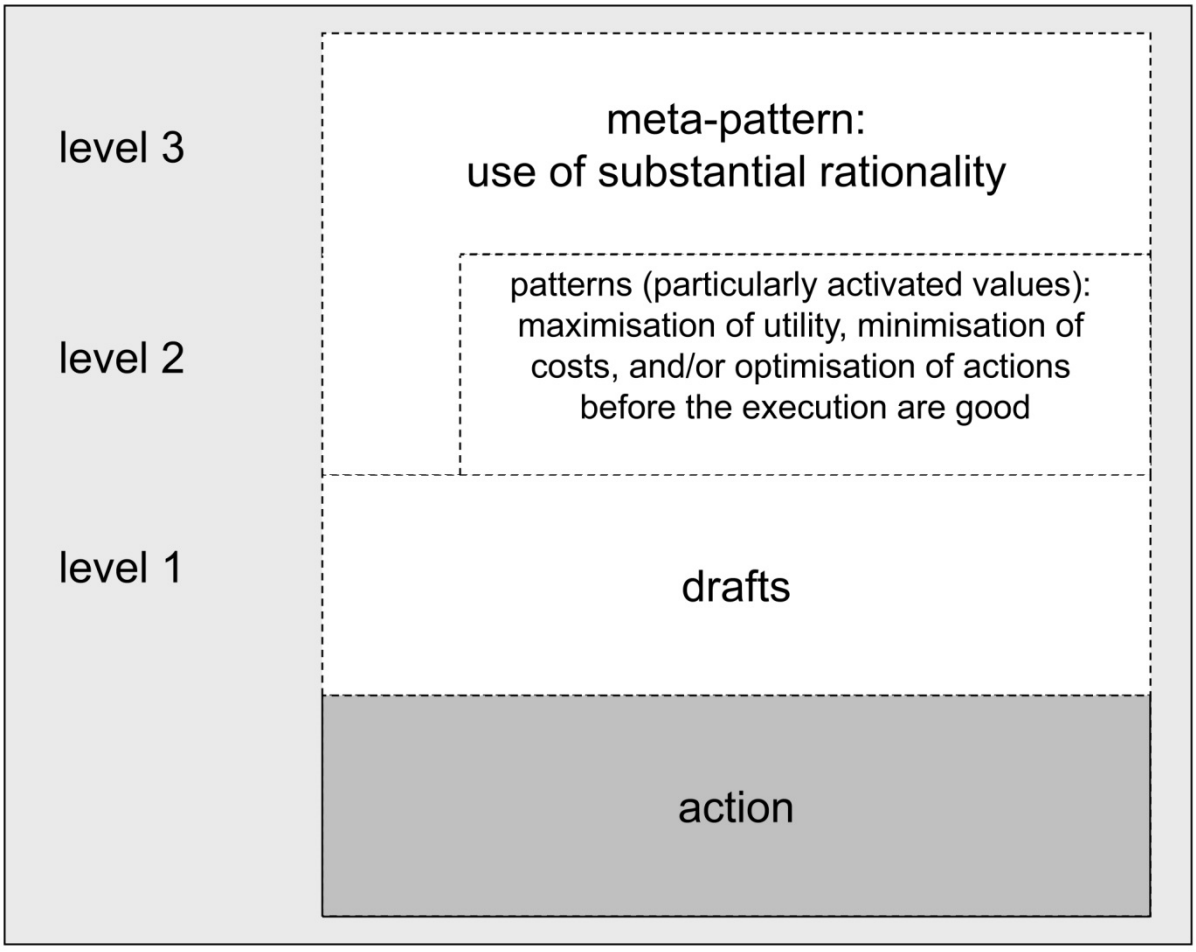

Figure 15 Exemplary decision framework of an ideal type 'rational-calculative' agent.
If an agent chooses rationally, the meta pattern of using substantial rationality is activated and the decision process reaches conscious optimizations of available information. There is a choice between the various patterns to select the optimal draft for execution and subsequent action (Kominek, 2009).

To map whether such a decision process is different from the ideal type automatic-spontaneous one, two more levels are added to the model frame, level 2 and level 3. Level 2, the level of patterns, contains decision criteria such as moral values, goals, norms, abstract models, prejudices, and other knowledge or information that are evoked, rejected, or enriched when considered in decision processes. Level 3 contains meta-patterns that control the inner process of decision making. With regard to the level of inner stress, routines or agents' individual decision making, they let the decision process run shorter or more slowly, expand or flatten it, make it more or substantially less rational or controlled by anxieties, goals or values.

However, as the dashed lines indicate, the use of levels can be interactively flexibly combined.[11] The differentiation between levels 2 and 3 only allows a clear arrangement and indication of two fields of analyses, one concentrating on the content (level 2) and one on the process (level 3). These two ways influence the decision process and possibly also the decision result and therefore have an impact on the resulting action. Consequently, the suggested model merely offers a framework for subsequent analyses.[12] Using this framework, the *ideal type rational-calculative* can be described (Figure 15).

4.3.3 Deductions from the Macro-Level Path to Micro-Level Decisions

Emission paths of high or low rate are only observable at the aggregated macro level. But according to general path dependency theory it is not possible to predict outcomes before the lock-in. And in the state of lock-in any action is practically stuck and therefore predictable, and it cannot be flexibly changed anymore. Therefore, it is of particular interest to deduce the single agent's decisions at the micro level from macro-level information in order to predict dynamics that can then either be prevented, changed, or strategically intervened in.

[11] This is different from Esser's model of frame selection where a clear chronology is assumed, in which different levels are passed with the steps of a modus selection in between. In a modus selection the agent decides more or less consciously whether the partial decision on the next level would be chosen in an automatic-spontaneous or rational-calculative way (Esser, 2005).

[12] An attempt is made to make the lowest possible number of assumptions, and in particular fewer than in rational choice models.

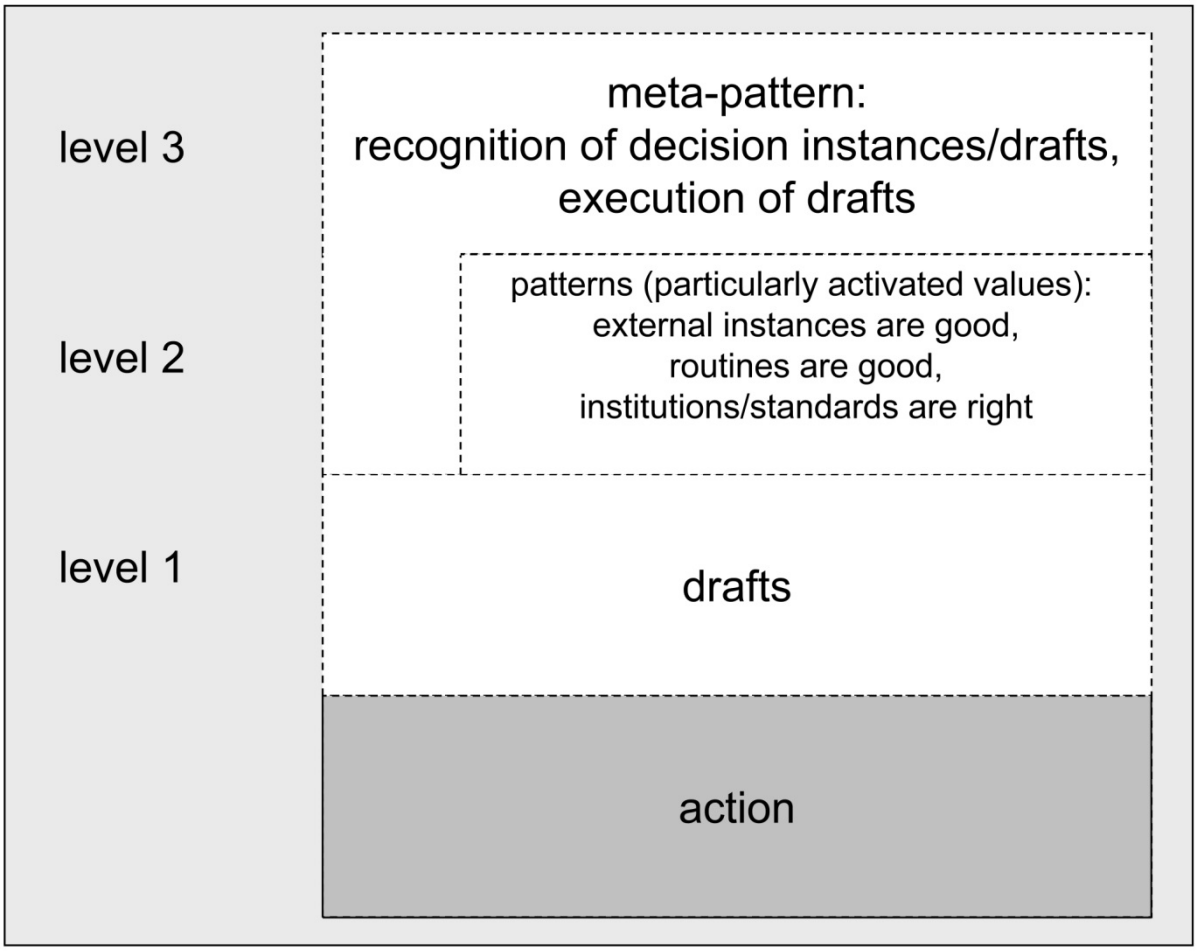

Figure 16 Components of the decision-making process of an 'ideal type path dependent' agent activated (and created) by path dependency.
The behavior of following individual experts can be described as the recognition of decision instances and the execution of a draft. If level 3 is reached in the decision-making process it refers back to levels 2 and 1 with the advice to follow routines and institutions and more or less simply execute the drafts. The final selection of the action draft occurs in a routine way (Kominek, 2009).

Whatever it is that causes similar actions that can be understood as the following of a path, that way of acting becomes more and more of a habit. It is possible to shorten a decision process by merely following a habit without thinking any more (on levels 2 or 3), or evoking further (or any) decision criteria. Because of the least-effort principle (in social psychology; Moskowitz et al., 1999), this shortening of decision processes is what occurs if a path is followed for a longer period of time. Thus, the more path-dependent decisions an actor reaches, the more his process of decision-making is just a matter of following some routines or rules because the process of having and applying habits or routines has itself already become a habit (according to the least-effort principle; Moskowitz et al., 1999). Of course,

this is a very detailed description of a self-reinforcing process, because a habit or routine gets reinforced in the way described. But this psychological analysis is necessary to reach the conclusion that an ideal type path-dependent can be used in a way that may be compared with an ideal type rational-calculative in order to expand multi-agent models.

What happens when this agent who acts path-dependently is confronted with a previously unknown situation, e.g. if the tenant of an apartment smells emissions from her switched-on heating system in the bathroom? The agent either simply continues to follow the same routine she always uses: to switch the heater on and to leave it on as long as necessary, or the agent does what she usually does when confronted with a new situation (which is almost like a routine on level 3): she turns the heater off again or leaves the room to return to a familiar situation. Alternatively, the agent needs a new routine to match the new situation, e.g. she could open the window. A quicker (or more successful) strategy for an agent than generating a new routine for herself is the adaptation of (successful) routines, rules, and standards from other decision instances, e.g. she asks a neighbor how to deal with the smelly heating system. The neighbor might suggest calling in the caretaker as an expert to fix it.[13] So again, according to the least-effort principle, the agent more and more tends to prefer this external adaptation of routines instead of generating them herself. This manifests itself in the inner decision process and in the decision criteria. It is even quicker to merely adapt drafts that only need to be executed than to adapt full routines, as it is not necessary to remember to always call the caretaker immediately when there is trouble with the heating, but the neighbor may suggest this action again if asked another time.

It can be concluded that agents who encounter a new situation, such as the one that is stimulated by climate change, are likely to rely on others in their behavior, especially on locally available individual experts (Simon, 1983). The likelihood for this behavior depends on the intensity with which path dependency has previously affected the agent, e.g. through local social structures, routines, tradition, or culture. As a consequence of this analysis, an *ideal type path-dependent* can be defined. This means that the more an actor tends to decide and act path-dependently, the more his decision-making processes tend to resemble ideal type path-dependent behavior (Figure 16).

[13] These effects can be monitored as complementary effects of path dependency or conformity tendency in e.g. organizational fields (Sydow et al., 2009).

4.4 Modeling of Evolving Strategies

Now the characteristics of an ideal type path-dependent can be used to model scenarios or predict behavior with the accuracy of people being affected by path dependency. Related to this topic, it can be stated that if global climate policy increases the institutionalization and thus the effect of path dependency on single agents (chapter 7 of this thesis), it reinforces their tendency to act like an ideal type path-dependent. So, what social dynamics or group behavior would result?

The following example describes how the ideal type path-dependent can be included in the expansion of an agent-based multi-level model to make predictions. The more the applied decision processes resemble those of an ideal type path-dependent, the more the agent under consideration tends to follow others instead of computing complex solutions himself, e.g. migrating where others migrate when affected by climate-change-induced flooding or water scarcity, or fighting those whom the others fight if local experts also do so. Such results, stemming from the behavior of ideal type path-dependent agents, can be modeled. And then, using the probability of these agents being affected by path dependency, their action can be predicted. Simulations of social dynamics resulting from the behavior of ideal type path-dependent agents can then be used to develop and optimize intervention or even prevention strategies.

4.4.1 A Multi-agent Model

To get an impression about group dynamics resulting from path dependency, some effects are now considered in a multi-agent model. The *value-cost-system* (VCX) model, a dynamic multi-agent interaction model, is used as base model, considering single agent action (Scheffran & Hannon, 2007).

With some mathematical notation it can be described as follows.

Each action takes place in a system environment x, where costs C_i invested by agents A_i produce values V_i. Considering a given time t, the present system state would be $x(t)$, present costs $C_i(t)$ and the resulting values related to the same point in time $V_i(t)$. Then a group of n agents $A_1, A_2, \ldots, A_n$ can be considered, in which each agent acts through investing costs and receiving values.

If agents have target values V_i^* that they try to reach and that therefore serve as goals, they can be considered as learning in an adaptive way in order to approach their individual goals. When considering not only one point t in time, but stepwise action in a time sequence, the following point would be $t+1$, the subsequent one $t+2$ etc. (while the previous one would be $t-1$ and the one before $t-2$ and so on). So, if one assumes that this group of agents decides and acts rationally, one can let the agents compute efficiency rates and decide to use the most efficient cost investment to address their next-step target values $V_i^*(t+1)$.

This basic model then can be expanded and applied in order to model conflict situations such as environmentally-induced fishery problems (BenDor et al., 2009), or arms races and international stability (Scheffran, 2001; Scheffran & Hannon, 2007). Furthermore, it can be used to model climate games, e.g. in the case of emission trading (Scheffran, 2004) It is possible to calculate the implications of global emission goals for the regional or local levels, based again on the rationality assumption of each interacting agent.

Applying the previously described perspective of path dependency, the following behavior of ideal type path-dependent agents is considered in an expansion of the VCX-model, and the effects of path dependency are analyzed.

4.4.2 Inclusion of a Following Behavior in an Expansion of the VCX-Model

Assuming transparency within the group considered, a single actor A_j may look at choices made by other actors during the previous time step and the results that they achieved. Then she follows the actor whose action would have contributed most to reaching A_j's own goals.

Thus, the decision rule is to do in the next step what the selected actor has done in the step before. This decision rule (0) can be formulated for each agent A_j as follows:[14]

$$C_j(t+1) = C_{i_0}(t) \qquad (0)$$

where i_o is defined as:

$$\left|V_j^*(t+1) - V_{i_0}(t)\right| = \min_{i=1\ldots n}\left|V_j^*(t+1) - V_i(t)\right|$$

This particularly makes sense if costs are not only a monetary amount but a complex combination of resources, and the causal relationships between resource combinations and individual goals is not evident to the single actor. A consumer cannot know exactly which products or product combinations produce what amount of carbon emissions because companies may optimize some aspects of production such as transport in various ways without mentioning data on the associated emissions. Instead of testing the complex situation for successful resource combinations himself it appears to be more appropriate for the agent to also use others' experience as described above, because other agents might have had better information about which products produce more emissions than others.

This method of decision-making and acting can be described as a procedure that especially makes sense in complex real world situations when transparency between actors can be used to better address one's individual goals, rather than just searching for the best action by trial and error oneself. This is particularly true if the positive or negative outcome for the individual is only recognizable long after the actual action, as in the case of climate warming effects due to major heating systems or industrialization.

However, following this procedure has an important limitation: while theoretically each imaginable complex resource combination may be used for a different next-step action to address an agent's goals, in the procedure mentioned above only the previously used combinations, that is, a finite number, are allowed for determining the next action. If all group members decide to follow this kind of procedure, the number of action options can only be reduced over time and not expanded. And the group may end up all doing the same thing.

[14] If the agent has a longer memory than just one period, the term $V_i(t)$ could be replaced by $V_i(s)$ whereas s runs through former periods t, t-1, t-2, … through each time period the memory lasts.

This can be good as the resulting action may be the best action locally available for each single actor to address their individual goals, such as the reduction of carbon emissions or the survival of a drought or a flood. But compared with the infinite number of possible actions it is likely that the action chosen is suboptimal and cannot be improved over time if the agents stick to the decision-making procedure described.

Of course, the procedure could be improved if an actor did not only consider copying what she herself or other actors did before. She could use these actions as a basis for computing new actions to best address her goals. Then there are still some limits as to how far she deviates from her former experiences or whether she sticks close to them, but at least new actions can improve group members' future actions. But if the action basis already consists of too many similar actions, even their combinations will remain similar (e.g. if all actors acted the same way, then the combinations of their actions would stay the same as well). Examples could be two types of preferred apples around the world that can be imported from different locations, or that people who use the same type of heating system might use it in smaller or larger versions and thus somehow optimize the production of carbon emission per apple or heating system. But depending only on those two types of apples and the one style of heating system would be a narrow frame for optimization and it is likely that emissions could be reduced far more effectively if further actions were considered, such as different local fruits or geothermic or photovoltaic solutions for heating.

4.4.3 Effects of Path Dependency

You can conclude from the former analysis that the more an agent is affected by path dependency the more his decision-making processes become similar to that of an ideal type path-dependent, that is, the more he decides and acts in routines, or follows institutions, standards, or external decision instances when applying action drafts.

Returning to the multi-agent example of decision-making, the process of following others can be enhanced with institutions, standards, or abstract decision instances, e.g. by the mass of agents that can be followed. This way it is possible to deduce that the more path dependency affects an agent, the more he fits his decision-making processes within the described multi-

agent example. Thus, institutions, standards, and abstract decision instances can be added into the line-up of action options. This also holds for actions that oppose a standard or institution when mapping agents' behavior. This may be quite a long line-up, but the single agent is still considered to be affected by path dependency. Therefore, whatever agent, institution, or abstract decision instance he chooses as a basis for his actions, the reselection of this type of decision basis for his actions (as described above in an abstract sociological way) becomes again a habit or routine and further reduces the range of his future actions.

For example, if a consumer intends to reduce carbon emissions she may follow the standard of purchasing organically grown products (biologically produced goods), hoping that they were produced in sustainable ways. She would therefore buy a bio-apple or bio-T-shirt. Maybe a good friend of that agent would then tell her that the annotation 'bio-' does not necessarily include regulations on carbon emissions and that he or she would rather buy a locally produced apple or second-hand T-shirt. A colleague may then say that mass production tends to reduce carbon emission per product, because logistics and energy cycles can be optimized to a greater degree. And an NGO such as Greenpeace may suggest ignoring the products of a certain company to punish it for unsustainable behavior. So, regardless of the decision instance the agent chooses as preferable (a bio-label, a personal good friend, a colleague, the mass of the population itself e.g. from nationwide statistics, or an NGO like Greenpeace), acting according to that preferred decision instance again becomes a habit.

The reduction of variety in executed action is observable not only in historical recollections. Furthermore, the agent's points of view are more and more reduced as his actions are shaped by routines and when focusing on only a limited number of relevant institutions or decision instances is necessary for his action.

It can be concluded that even though theoretically an infinitely large variety of actions is available, path dependency more and more makes agents act within a very limited range of actions, believing more and more that these are the only actions they can take. Thus, global climate policy can lead locally to a reduction of action variety and therefore an increase in polarization. And in this context, even further conclusions on the strengthening of hierarchical structures can be drawn.

4.5 Situational Intervention to Prevent Climate Change and to Enhance Mitigation and Adaptation: Implementation of Chosen Strategies

4.5.1 Political Structures Evolve and are Reinforced Through Path Dependency

It can be deduced from the previous sections that as long as agents are affected by path dependency, they tend to more and more follow routines or other decision instances in their actions, and even to focus their attention on them and disregard potential alternatives. This implies that agents who follow others pass on their negotiating power and legitimations to their (collective) master. In the previous example the agent either follows the bio-label, the personal good friend, the colleague, the mass of the population itself, or an NGO. So whatever decision instance the agent chooses to allow his actions to be influenced by, by doing so he yields the power to influence his actions to that particular decision instance. The effects that result from following that decision instance acquire additional authorization via path dependency, and consequently that decision instance becomes empowered to influence the agent's future actions as well. In this way, Greenpeace, for example, acquires negotiating power, social networks acquire a hierarchical structure, and traditions are reinforced. An increase in path dependency tends to reduce an agent's master options over time, and manifests social structures as hierarchies. Therefore, path dependency tends to increasingly prevent agents from taking rational decisions based on content issues, and makes them followers within the social structures instead. Through path dependency, micro-politics increasingly matter more than content.

Combined with the continued reduction of the range of alternatives under consideration caused by path dependency, path-dependent negotiating processes are likely to end up in political conflicts as they only focus on a small range of alternatives in the political debate, resulting in the situation that each party regarding the conflict usually only holds one particular view on an issue. Accordingly, global climate policy can reinforce national, regional, or local conflict structures and thus lead to an intensification of existing local conflicts around the world. And even more global conflicts could evolve as polarization increases and hierarchies are strengthened. But knowledge of path-dependent action not only

allows for conflict prediction, it also can help intervention strategies to be applied more efficiently, using local structures and self-reinforcing dynamics.

4.5.2 Situational Intervention: Examples of the Implementation of Strategies

If strategies evolve and are to be executed, situational intervention needs to deal with social structures and dynamics that result from path dependency and to some degree affect the agents' future actions. It may happen that social structures prevent direct intervention, e.g. political systems prevent monetary aid from reaching affected agents because the money is spent to enhance existing political structures, something which might happen under totalitarian political regimes.

Other effects may be self-reinforcing learning effects within populations on how to best cope with floods or water scarcity. The Dutch are enlarging their dikes to adapt to a rising sea level resulting from climate change (Klein et al., 2001). Some coastal zones may use early warning systems to help people leave coastal housing in time to survive potential disasters (Adger et al., 2005, p. 1038). They may also expand the knowledge of how to rebuild destroyed houses after a flood quickly, or how to move to more secure places at higher elevations. African pastoralists have the traditional knowledge to leave dry places and move on with their families and animals to oases where they still can expect to find some water (Berkes et al., 2000). If all pastoralists share the same knowledge they will likely end up in the same places. Then the water may be insufficient to support all the people at the same time (Njiru, 2012).

When people increasingly follow others, additional effects can occur. These could include cascading actions or mass migrations. People around the world see on TV or are told on the radio or by people who have travelled how other people live. And many would like to improve their living standards (e.g. India/Bangladesh). Others are affected by floods or droughts, and have lost their crops and/or homes (Kates et al., 2006). Depending on their own situation, families or villages either send out their most talented members to earn money elsewhere to ensure the survival of the collective (e.g. Mexico; cf. Lindstrom, 1996), or they all migrate together if, for example, their entire land is lost (e.g. Pacific Islands; cf. Barnett, 2001). And in less affected regions democratic behavior can evolve and result in conflicts

between parties who block early prevention even though technology and capital would have been available (Tol et al., 2003).

For this reason, it is desirable for intervening strategies to respect existing social dynamics rather than to work against them. Existing interests in improving living conditions could be enhanced to help people migrate and become educated in an integrative way. Traveling family members could be educated and helped to return home regularly so as to improve adaptive knowledge and the use of early warning systems, situational documentation, and aggregated local knowledge. And if collectives such as populations from the Pacific Islands migrate together, knowledge about their hierarchies, traditions, and spiritual celebrations may help to find or create integrative solutions for them (Böge, 2008, p. 12).

The implementation of strategies is more promising when local agents are included instead of being excluded. So intervention strategies should be directed towards, for example, the destination regions of migrants, towards the enhancement of the variety or spread of best practice using modern scientific knowledge and best technology, or towards avoiding structural blockades. Thus, local and regional social dynamics that result from path dependency could be adequately considered and used to better mitigate and adapt to climate change. Nonetheless, the concepts of centralized global climate institutions should be handled with care because an increasing institutionalization at the global level affecting all agents around the world can intensify local conflicts.

4.6 Conclusion

The WBGU (2008) identified four major conflict constellations: climate-change-induced degradation of freshwater resources, climate-change-induced decline in food production, climate-change-induced increase in storm and flood disasters, and environmentally-induced migration, all of which are likely to cause conflict. But in addition to conflicts as the reactions of people who are directly affected by changes in environmental conditions, another level of potential conflict intensified by climate change, or rather policies addressing its causes and consequences, needs to be considered. Conflict may result as a side effect of debating,

communicating, and implementing particularly policies aimed at the prevention, mitigation of, and adaptation to climate change.

This chapter has argued that global climate policy, which selects one particular strategy among many to address climate change, can lead to an intensification of national and local conflicts around the world. The argument is based on the assumption that path dependency shapes human behavior. Using an expanded multi-agent model it has been demonstrated that, via path-dependency effects, decisions at the global level can result in a reduction of the variety of action applied locally. Furthermore, this perception of diminishing options can coincide with an increasing radicalization of positions and a reinforced strengthening of existing social hierarchies. If disturbed through climate-change-induced disasters or revolutions, path-dependent structures are likely to re-evolve in an even more intense way, which means that the people involved tend to act even more in ways that are best explained by path dependency.

This chapter has focused on expanding existing path dependency theory to include micro-level effects, outlining a theoretical model and giving a few supporting examples. More empirical work is needed to confirm this analysis by investigating whether individual agents decide and act as predicted by path dependency theory with regard to the topics addressed. If more empirical information about the importance of path dependency were available, this theoretical approach could be used to estimate the local side effects of global climate-related policy, such as the exacerbation of international, national, and local conflict. Furthermore, models that include path-dependent behavior may help to optimize intervention strategies; they do this by considering the inception of self-reinforcing processes and thus the direction of leverage effects on peaceful dynamics that are generated in a particular way, and that aim at mitigation of or adaptation to climate change.

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5 Cascading Processes and Path Dependency in Social Networks

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5.1 Introduction

Cascades can have strong effects when they occur. One example is the economic crisis of 2008 caused by reckless lending practices of financial institutions, followed by the Greek credit crunch where the interaction between rating agencies and governmental responses created an explosive situation. Another example is the series of protests in North African countries in early 2011 where the food price is supposed to have contributed to instability in this region. The cascading potential of natural disasters is vividly demonstrated by the March 11, 2011 earthquake in Japan, which triggered a chain of events. These include a tsunami wave travelling across the Pacific and a nuclear reactor accident spreading radioactivity into the atmosphere, forcing people to evacuate from the region, not to speak of potential implications for the Japanese power grid, stock markets, the oil price and the economy in general. The shock waves of the disaster even affected German politics by triggering the election of a Green Party Prime Minister in one of most conservative federal states. This indicates how many factors interact in a complex way in such a disaster with implications across continents.

How can these cascading effects be explained? It may be useful to refer to an everyday experience that vividly demonstrates how things can go wrong. In the TV comedy sketch "Das Bild hängt schief" the German humorist Loriot shows how human-environment interaction can result in a cascade that leads up to a destroyed environment in the end. Starting with the attempt to align a skewed picture on the wall, Loriot's pedantry to create order ultimately triggers and enhances a cascade that leaves the room in a chaos. He could have

stopped the process by accepting the current state, but instead he is caught in his behavioral scheme that further enhances the cascade. Such behavior of sticking to what one is used to do although one is free to choose alternatives (David, 1985) has been discovered in economic contexts and described as path dependent behavior.

In this paper expanded path dependency theory is used to explain self-reinforcing processes in social dynamics. In that approach path dependent social networks are considered in which connections of the social network and the tendency to follow the social network can be reinforced. The path dependency perspective can be used to describe individual behavior on a micro level as well as institutions on a macro level. Within this framework, a self-reinforcing path dependency spiral could increase the potential risk for social cascades in each step. With this setup it is possible to study the impact of triggering events (e.g. natural disasters, mass migrations, or social movements), and find cascading sequences and tipping points.

In the following, general social network theory is presented with a focus on network diffusion and threshold concepts. Then two types of cascades are defined. We distinguish between informational cascades that explain a following behavior of individuals and inter-systemic cascades that describe the spillover effects from one system to another. While the first one is more applicable to analyze the behavior of demonstrators, the latter one is more adequate to describe the effects that are triggered by a natural disaster.

Then an expanded path dependency framework is presented. The more people are affected by path dependency, the more they tend to follow others, which can be described in special social networks. The self-reinforcing character of path dependent processes can be used to define path dependent social networks (PDSN). This framework is applied to several examples of recent cascades. These include the North African protest movements, and the aftermaths of the Japanese earthquake. In addition, we will briefly discuss potential future cascades induced by climate change. From these analyses in the PDSN framework an impression of people's tendency to act path dependently in these situations can be deduced. It is further shown how the PDSN concept can be used to describe social dynamics within groups and to explain observable cascades. We will then sketch a conceptual approach of the PDSN that may be used in the future as a basis for modeling and simulations.

5.2 The Context of Social Network Analysis

The study of social networks increasingly shapes many fields of social interaction. Social network analysis (SNA) is an evolving methodology in the social sciences (Wasserman & Faust, 1994), used to study a variety of social phenomena and processes. One focus is on how agents dynamically interact with each other and create their social environment by building links between the agents who act as network nodes.

5.2.1 Diffusion on social networks

An active field of research is the dynamic spread of processes across a social network depending on the network structure. In this context some topologies are particularly relevant, e.g. the small-world network that describes a network structure, in which everybody is closely linked to everyone else and thus a high diffusion rate of information is likely. Often researchers try to find the most central agents in a network, e.g. they attempt to optimize the spread of information across the network. The relevant network structure might change when switching focus between different dynamical processes. Unfortunately, "the relationship between network structure and dynamical consequences is anything but straightforward" (Watts, 2004, p. 256).

Particularly important is the study of diffusion processes. Models of network diffusion (Kempe et al., 2005) describe the spread of diseases (e.g. of the H1N1 virus) as well as the spread of social behavior patterns like innovations, practices and conflicts. These are similar to basic models of disease diffusion such as e.g. SIR-models[15] (Kermark & Mckendrick, 1927) or models of viral marketing. Different are models of social contagion (Dodds & Watts, 2004):

[15] SIR stands for Susceptible – Infectious – Recovered.

> "Unlike SIR-type models, however, which assume contagion to be a memory-free process, individuals making decisions are affected simultaneously by past as well as current interactions […]; hence, the cumulative probability of 'infection' exhibits threshold-like behavior." (Watts, 2004, p. 260 f.)

This threshold-like behavior might also be relevant when analyzing diffusion of path dependency and social cascades related to it, because in path dependent processes history matters. There are different approaches using threshold models describing collective dynamics other than the stylized SIR-type (Dodds & Watts, 2004; Granovetter, 1978; Granovetter & Soong, 1983; Schelling, 1978). In a model of social contagion, for example, it can be shown that the diffusion rate, and thus the risk of global cascades (or epidemics in the viral terminology), relates to the topology of the network. In a sparse network, global cascades are most likely when the network connectivity is neither too low nor too high (Watts, 2002).

> "It is the latter condition that is surprising because in biological contagion greater connectivity always implies a greater possibility that a disease will spread. In social contagion, however, dense connectivity renders many individuals impervious to novel signals, thereby quashing cascades before they can even begin." (Watts, 2004, p. 261)

Thus it is interesting to see which dynamics may result depending on the network connectivity and certain events (e.g. a disaster or credit crunch) that affect key variables in the emerging path dependent social network. Bonabeau (2002) presents arguments for analyzing emergent phenomena and emphasizes that agent-based models are useful to consider complex evolving processes and gather information on complex causalities to discover perhaps otherwise unoccupied connections. Models of network diffusion, developed to analyze the spread of diseases, can be used to study the spread of social behavior patterns, such as the proliferation of violence as well as the diffusion of technical and economic innovations or of environmental and social practices. A new field of research is the application of SNA to the spread of conflict (Flint et al., 2009; Maoz, 2010).

5.2.2 Cascades in social networks

In pursuing their individual interests, collective interaction among multiple actors could lead to a "cascading sequence of events where an action taken by one actor provokes more intense actions by other actors" (Scheffran, 2008, p. 19). Social science research has focused on informational cascades that occur "when it is optimal for an individual, having observed the actions of those ahead of him, to follow the behavior of the preceding individual without regard to his own information" (Bikhchandani et al., 1992, p. 992). Likewise a cascade is described and modeled in a way that agents learn from the behavior of other agents and thus follow them in the way they act (Bikhchandani et al., 1998), thus leading to a collective transition.

For instance, if in a line of agents the second agent follows the action of the first agent, the third one will copy the behavior of the former two, and so forth, until the whole line ends up in performing all the same action (Bikhchandani et al., 1992). The local rules of following neighbored or observed agents allows the study of social dynamics, an approach that has been applied to phenomena like herding in financial markets (Banerjee, 1992; Scharfstein & Stein, 1990; Welch, 1992). Real-world examples of informational cascades can be found everywhere, from the stock market and voting patterns to the fashion industry. One explanation why humans put so much attention to choices made by others is that "imitators may have as high a long-run 'fitness' as optimizers" (Conlisk, 1980, p. 275). Richerson and Boyd (1992) show that in many instances social learning is preferred by natural selection. If the choices and actions of others influence our own decisions, with an increasing size of the population tipping points in collective interaction may become more likely, possibly undermining the stability of the entire system.

Tipping points are also relevant in inter-systemic cascades in human-environment interaction. According to (Urry, 2002, p. 8), tipping points involve three notions: "that events and phenomena are contagious, that little causes can have big effects, and that changes can happen in a non-linear way but dramatically at a moment when the system switches". Seemingly *minor* events could provoke major qualitative changes of the system, which is characteristic for chaotic systems. A self-reinforcing chain reaction could increase the potential risk for social cascades that could put the whole system at risk.

In order to study the likelihood and the possible implications of social cascades, various tools have been developed in complex systems sciences that allow analyses of social phenomena in the human-environment interaction (see Scheffran, 2006). In particular, they can help to assess the impact of human responses to environmental change and the social interactions that result from these responses. For a large number of homogenous actors, methods from non-linear dynamics have been used to describe phenomena of complex adaptive systems such as self-organization or micro-macro phase transitions (Helbing, 1995; Schweitzer, 1997; Weidlich, 2000). Agent-based modeling (ABM) analyzes patterns of collective action emerging from large numbers of agents following particular rules of behavior. Depending on stimulus-response mechanisms on the micro level, complex social patterns can emerge on the macro level. ABMs may be useful in situations where the future is unpredictable and traditional analytic methods for decision-making are least effective. Applications range from moving crowds and traffic systems to urban, demographic, and environmental planning (Billari et al., 2006). Unlike game theory, in which the selection of options is determined by the rule of optimizing utility, ABM selects rules to adequately describe real-world decisions. Multi-agent models have gained increasing interest in social modeling, taking into account the adaptive, disaggregated nature of human decision-making as well as collective responses to changing environments and management policies.

5.3 The Explanatory Framework of Path Dependency Theory

The theory of social networks and cascades can be related to path dependency, an established concept which implies that social actors tend to be locked in on certain pathways of action, around which self-reinforcing mechanisms prevent individual change (Beyer, 2005; Sydow et al., 2005; 2009; chapter 7 of this thesis). The terminology of path dependency is promising as a basis for the analysis and modeling of social diffusion and cascading processes.

5.3.1 Theoretical context of path dependency

It is a common observation that on markets not necessarily the most efficient technology dominates but the one that has historically been ahead of others (Arthur, 1989, 1994), as is the case for the QWERTY-keyboard. It is international standard regardless whether it matches present efficiency criteria or not (David, 1985, 2001, 2007). This phenomenon of path dependency can be characterized as *history matters*, which implies that former events influence later ones and that sequencing is relevant. Transferred into the social context (Mahoney, 2000) and the political context (Pierson, 2000) it is debated whether or not a sociological approach is necessary to expand the economic argument of rationality (Liebowitz & Margolis, 1995) or whether it is even applicable to institutional processes (Alexander, 2001).

Present approaches focus more on the process-oriented view of path dependency, describing the relevance of a human-centered approach, e.g. in organizational studies (Sydow et al., 2005, 2009). In this context, a *path dependent process* is defined as a self-reinforcing process with the tendency for a lock-in (Sydow et al., 2005, 2009). While former approaches concentrated more on historical analyses (thus backward looking assessments) of event sequences, the approach of *path creation* argues for a more forward looking research considering the beginning of an evolving path and options to shape it deliberately (Garud & Karnøe, 2001). Still, all these approaches consider path dependency as a macro-level phenomenon involving agents in an aggregated way.

An extended approach connects the macro level phenomenon of path dependency to effects on single agents at the micro level (chapter 4 of this thesis), using concepts from social psychology (Chaiken & Trope, 1999; Moskowitz et al., 1999). Accordingly, multi-level approaches can use path dependency as a diffusion variable in ABM for analyzing complex scenarios and no longer have to stick to a very simple understanding of path dependency (Welch, 1992) or approach path dependency by simulating likewise phenomena (Janssen & Jager, 1999). Thus, combining the micro level foundation for an informational cascade with path dependency theory, it generally can be said that the more an agent is affected by path dependency, the more likely it is to *follow* other agents and thus to participate in an occurring cascade.

5.3.2 Path dependency in social networks

A deduction from the macro level phenomenon of path dependency (chapter 4 of this thesis) results in the following causality as perceived by the agents: The more an agent is affected by path dependency, the more the agent's behavior tends to resemble *ideal type path dependent* decision processes. This implies that the agent increasingly tends to follow external decision instances instead of optimizing decisions according to own internal preferences. The agent's behavior of following others can be mapped in a PDSN. The tendency to decide and act path dependently can then be described by the likelihood to follow one of the network neighbors in the agent's PDSN. The self-reinforcing characteristic of path dependent processes results in an increasing likelihood to follow others: If an agent behaves path dependently and follows one of the individual PDSN, the behavior to do so will get reinforced. This means that if the agent is in a comparable situation, he/she will tend to follow the PDSN again, even more than before.

Additionally, if the agent follows a PDSN neighbor within the weighted social network, the tendency to follow that special neighbor will get reinforced. This implies that the tendency to follow that neighbor again the next time in a similar situation is more likely than before. In such a step of increasing tendency to follow others the amplitude of the single effect depends on the past events that already have coined such a behavior. While in the beginning of a new coined behavioral path the tendency to behave alike may be very low at first but exponentially growing (primary-like socialization), the tendency increases at a diminishing rate subsequently (secondary socialization, chapter 7 of this thesis). Therefore, if an agent follows its new neighbor within the PDSN, the next time the neighbor will not be unknown to him anymore. And over time, if the agent follows that neighbor more than once, the agent will possibly appreciate that behavior and maybe choose that particular neighbor as an individual expert on some topic. E.g. if the agent repeatedly asks a PDSN neighbor when having trouble with her computer, that neighbor will possibly become the agent's personal computer expert over time. But if the advice of that potential expert has proven wrong, the agent will more likely still listen to the advice the next time, but act in an opposite way. Therefore, whether you accept or reject your neighbor's advice is a result of the previous experience.

5.4 Examples of Applications

5.4.1 The protest movement in Egypt

One example for a cascade that can be described through collective group behavior among path dependent agents is the spread of protest movements in the Arabic countries in North Africa and the Middle East in early 2011. Starting with riots in Tunisia, which forced the president to flee, the revolutionary impulse expanded to Egypt and other countries, accelerated and multiplied by electronic media and social networks in the internet. These facilitated the quick spread of successful experiences to motivate neighboring agents to join in the revolutionary behavior and best practice on how to protect from police or military intervention. In a report on German TV[16] an interviewed activist mentioned that his and his companions' idea of a peaceful revolution goes back to the peaceful revolution in Serbia.

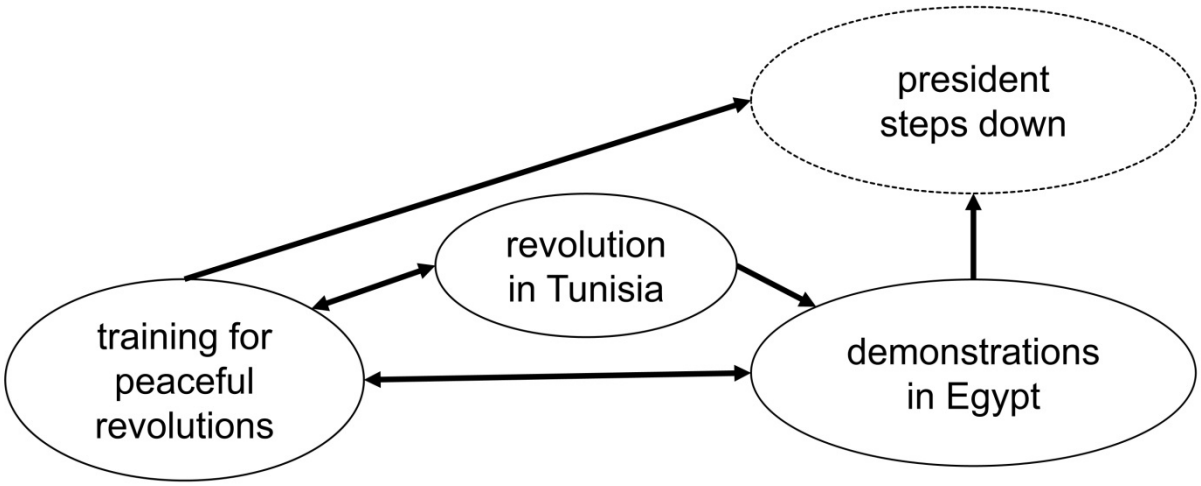

Figure 17 Cascading sequence of events leading to the revolutionary developments in Egypt.

This refers to a book written by Serbian experts on 50 steps towards a peaceful revolution, distributed through workshops on how to gain impact in the participant's home countries. Leading Egyptian activists have participated in those workshops prior to their revolution und used their training experience to start demonstrations in the slums of Cairo, winning masses of followers who were discontent with their present situation. By the time they reached the

[16] http://www.daserste.de/weltspiegel/beitrag_dyn~uid,s0ekpanjotxhviem~cm.asp

center of Cairo, they were a crowd of demonstrators, so that the police was unable to stop them. One example for intense following behavior is the peacefulness of the demonstrations on the Tahrir Square in Cairo. Although defenders of the regime used violence against the crowd of demonstrators, the demonstration remained peaceful in its self-organized resistance, which ultimately was successful in bringing down the regime of President Mubarak (Figure 17).

As deduced from path dependency theory, following behavior can be described in a PDSN framework to assess how path dependency impacts the resulting social dynamics to evolve. If a social network related action is chosen, the likelihood to follow the path of other agents will increase and the multiplier effect will contribute to a mass movement.

If the demonstration for cheaper food and jobs is started in a poor neighborhood, it is more likely that people watching will have a positive connotation to follow neighbors on that topic and walk with them in the demonstration. If a person joins the group, agents who are neighbored to the person in their PDSNs are likely to follow as well. In a different suburb without a positive connotation to the topic, people would more likely act contrarily and agents who are neighbored to them in their PDSNs would rather follow the latter, which means ignoring the demonstration, or calling the police.

Should agents walk with a demonstrating group, this act of solidarity contributes to several reinforcing mechanisms: attracting more neighbors to join the group, strengthening the PDSN, raising media attention, and increasing the relevance of the topic of the demonstration. Altogether, the group of demonstrators tends to grow in a swarming or cascading way until opposing tendencies such as counter-demonstrations, containment by the police or exhaustion by the demonstrators themselves prevail. As long as the pro-demonstration factors are successful, the movement tends to increase. If demonstrators have a high tendency to follow police orders, they will be likely to stop demonstrating and go home as soon as the police appears. If the demonstrators are attacked, their *action portfolio* will possibly switch from *peaceful demonstration for cheaper food and jobs* to *self-defense and survival*. If so, the attackers may become *new* PDSN-neighbors with a negative connotation, and other demonstrators will be likely to join in on defending their attacked PDSN-neighbors against the attackers.

Due to the intense correlation in their PDSNs, collective behavior could lead to rapid switching between different alternative modes of behavior, ranging from growing mass demonstrations to a sudden breakdown of the movement, should a different behavior spread. Thus, a once peaceful crowd can turn into a fighting mob when being attacked.

The fact that the Egyptian demonstration on Tahrir Square remained peaceful when being attacked therefore indicates that the crowd remained self-disciplined and prevented single agents' switching from *peaceful demonstration* to *active defense*.

This can imply that, by the time the demonstrators were attacked, potential followers were well focused on the peaceful strategy within their PDSNs and their path dependency was very high. Another explanation could be that the situation created herding instead of swarming, which would result in a collective mode of behavior in which demonstrators would not start to fight for their attacked companions but instead follow the mass at that time, disregarding individual participants. The high tendency to stick to herding and only help those attacked survive by medical support indicates a strong path dependency.

Besides these structural factors that allow observing a high level of path dependency, it may have been mere luck that the analyzed protests did not cascade more into a violent and conflicting direction as has instead been the case in Libya.

5.4.2 Impact of the Japanese earthquake on German politics

The massive earthquake that hit Japan on March 11, 2011 directly affected the Japanese society but had a more severe indirect effect through the resulting tsunami wave which killed thousands of people and blocked rescue options. Both events together caused severe damages on the nuclear power plants in Fukushima, which exploded and released significant amounts of radiation that affected large areas in adjacent regions. While the environmental effects have been fairly local, there have been global impacts and responses. For instance, national banks increased liquidity to prevent a serious recession at financial markets as a possible

consequence. Certain export products became scarce due to impaired production of some high-tech companies. Besides these local environmental and economic effects, social and political dynamics could be monitored far away from Japan, triggered by the cascading events of the earthquake.

Although Germany was not directly affected by Japan's earthquake, concerns over the risks of nuclear power reached a new all-time high after the nuclear catastrophe in Japan, which had previously been regarded as one of the most advanced countries when it came to the mastery of nuclear technology. This implies that the PDSN structures related to the topic of nuclear power use and risks of nuclear power disasters became increasingly recognized and reinforced. As a direct consequence, the German government immediately shut down the oldest nuclear power plants in the country for stress tests and launched an ethics commission to make recommendations on the accelerated phase-out of nuclear energy. Anti-nuclear energy protests boomed and parties that have been close to the nuclear industry were voted out of power, leading to the election of the first Green Party Prime Minister in one of the traditionally most conservative federal states.

As this example demonstrates, natural disasters can cause a cascade of local and global action chains affecting society in different parts of the world. The likelihood of spillover effects from one system to the next depends on tipping points in systemic interactions that involves both natural processes and social relations. And it is even possible that these relatively local short-term effects are topped by long-term radiation effects across the globe from the destroyed nuclear power plants in Fukushima.

5.4.3 Risk cascades of climate change

Climate change is a macro phenomenon that could simultaneously affect and challenge natural and social systems all over the world, thus containing the risk of multiple cascades connecting these systems. Considering climate change and its effects, there are many research efforts that measure, assess and model the natural processes, including atmospheric composition of gases and average global temperature, ocean dynamics, water chemistry, biodiversity etc. In comparison, there is a deficit in understanding the social dynamics in

response to climate-related events such as floods and droughts and in the identification of cascading sequences and tipping points in climate-society interaction. The complex causal chains can be constructed through a network of interconnections based on the sensitivities between key variables and actions (Scheffran, 2010; Scheffran et al., 2012c).

Climate change could possibly induce a wide range of individual and collective responses. There are numerous actors involved, acting according to their interests, capabilities and rules. Multi-agent settings are relevant when multiple regions, countries, businesses or citizens are affected by climate change and take individual or collective responses which lead to social interaction. At the global level of decision-making, the main actors are governments of nation states or groupings among them. At the local level, individual citizens and consumers are key players who affect or are affected by global warming. The multi-level process between local and global decision-making is connected via several layers of aggregation, with each layer having its own decision procedures for setting targets and implementing them into real actions. In a multi-agent setting, actors mutually adapt their targets, values, and actions to those of other players in order to change the resulting development in their own favor. But besides deliberately changing the behavior of oneself or others, structural effects such as those of the individual PDSN influence each agent's action. Thus, the collective action cannot be directly composed of individual targets and values but is a result of the social dynamics. Therefore, it is necessary to consider the steps in each agent's individual PDSN and its evolving dynamics.

While some dynamics may help a collective to jointly move forward, in the same instance, others may be negatively affected to move in the opposite direction and some targets may not be reached at all. For instance, in natural disasters, international aid may help the affected people to survive and thus stabilizes the social system. But aid in times of crisis may also lead to competition among or even struggle between those in need; actually, this has been the case in a few situations of natural disasters (WBGU, 2008).

With this setup it is possible to study the potential for cascading sequences of climate-related events (mass migrations, extreme weather events, food insecurity, social movements, and conflicts). On the other hand, this approach could be used to study the collective behavioral changes in a sustainability transition. Whether climate risk cascades will actually happen is

hard to predict. It may well be possible that climate signals only affect one layer in the causal chain but may not be strong enough to penetrate to other levels and thus fizzle out in the causal chain. Applications of this setup allow for the estimation of the probability of future destabilizing events occurring under specified conditions, which has implications for the development of a possible early warning system. Climate change could also lead to *path creation* in the sense of inducing new pathways that support a sustainability transition (Garud & Karnøe, 2001).

5.5 Conclusion

In this paper, an expanded path dependency theory has been used to combine social network theory and the concept of cascading events. When people are affected by path dependency they tend to follow others, increasing the risk of social cascades. Therefore, it is on the one hand interesting to obtain information about the intensity of the influence of path dependency on a single agent's actions. On the other hand it is interesting to describe in detail how cascades diffuse in social networks when the self-reinforcing mechanisms of path dependent processes are active.

In the case of the Egyptian demonstrations, social dynamics could be redrawn in path dependent social networks. From that analysis it can be concluded that the path dependency and willingness to follow the masses of the demonstrating crowd or other demonstrators must have been very intense because the demonstrations remained peaceful even after the demonstrators were attacked.

A cascade that lead to a nuclear disaster provoked political changes via spillover effects that increased opposition to nuclear power and induced a transformation of the energy system. That way external events as the earthquake or radiation problem in Japan influences social structures and future policy of a nation far away from the actual site of the disaster, as in the example of Germany. Although large impacting events as the earthquake in Japan may seem rare, explanations may help to better understand inter-systemic cascades and the connections and influences of non-social systems on social structures.

Furthermore, this framework may be particularly adequate to assess future risk cascades associated with climate change, and help to better understand, model, and simulate the associated complex social processes and their evolving dynamics. Thus, some key questions relevant for future research are: How do people react in scenarios of a (suddenly) changing environment? How do their institutions perform, for instance if the infrastructure breaks down and people's focus narrows down to the survival of individuals or families?

A new situation threatening a group of people can have different effects: Such challenges can result in reinforcing social structures that enable people to increase speed, self-effort and altruism in order to reach a group's survival as in a disaster. However, it can also result in competing and fighting structures as in the example of the revolutionary developments in the Arabic countries. But in all cases the actions increase path dependency and thus the likelihood of social cascades.

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6 Local approximation of path-dependent behavior: the *SHE-Model*

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Abstract

Path dependence shapes human behavior. But is human behavior predictable? Hardly – although it can be temporally locally approximated. The *SHE-Model* (Model of Swarming and Herding agents affected by an Environment), which is presented in this paper, simulates opinion dynamics and collective movement dynamics in a group of ideal type path-dependent agents who perform swarming or herding behavior.

Let's assume a path-dependent process exists that involves or affects agents, where a path-dependent process is a self-reinforcing process with the tendency towards a lock-in. What mathematics can be developed based on this definition and fundamental assumption? Corresponding to Coleman's boat, the first step of disaggregation from path dependence theory to the ideal type path-dependent has been deduced in a previous paper. This paper now focuses on the implementation of the ideal type path-dependent agents in a simulation model, which is the second step. In the third step, the *SHE-Model* again aggregates the dynamics back to the macro level. Completing Coleman's boat it can thus be said that if there is a path-dependent process affecting agents, social dynamics evolve that can be described by the *SHE-Model*.

Generally, on the macro level swarming and herding behavior occurs if there is a path-dependent process. Vice versa, simulations with the *SHE-Model* reveal that the simulated opinion dynamics are path-dependent processes. Thus, whenever there are opinion dynamics involved in a path-dependent process, these can be described by swarming and herding.

Accordingly, this proves that the ideal type path-dependent behavior implemented in the swarming and herding behavior in the *SHE-Model* is a basic element of path-dependent behavior. Therefore, the *SHE-Model* allows for a huge applicability to explain and describe social dynamics throughout society and the model can be used for the approximation of opinion dynamics and human behavior.

6.1 Introduction

In times of social media, swarm intelligence, post-truth politics, and alternative facts opinion diffusion dynamics rule the world. Who takes the lead and who follows? Social experiments reveal "(i) the expert effect, induced by the presence of a highly confident individual in the group, and (ii) the majority effect, caused by the presence of a critical mass of laypeople sharing similar opinions" (Moussaïd et al., 2013). Herbert A. Simon (1983) has already discovered that people like to have a personal expert to consult for advice. Thinking in more aggregated dynamics, swarming dynamics evolve from following a neighbor and herding dynamics result from following the masses. In a group consisting entirely of swarming agents, where each agent follows one other agent of the group, all move in cycles. If cyclical movement is excluded and there is exactly one non-swarming agent, everybody directly or indirectly follows that one particular agent. Is this behavior realistic for humans? Is this behavior stupid? Kominek explains that following behavior is not stupid but extremely optimized (chapter 4 of this thesis). Although it is not optimized with regard to the quality of the outcome, it is optimized by our brains with respect to the speed of decision-making. Using the least-effort-principle from social psychology, it is deduced that somebody who needs to take the same action decisions again and again rather uses a shortcut and just performs the actions instead of wasting time on lengthy decision-making processes again and again (chapter 4 of this thesis). This behavior seems very realistic at present, when everybody needs to make multiple decisions under time pressure. But what is the result? Path dependence.

In social sciences, a common understanding of path dependence is that "history matters": previous events shape subsequent ones. Path dependency theory has been coined by Arthur's research on increasing returns (Arthur, 1994) and David's case study on the QWERTY-keyboard (David, 1997). Arthur discovered that in markets competing product shares stabilize

over time. Seeking explanations for which technology wins in a market, Arthur introduced the theory of increasing returns "to show the process by which lock-in occurs and an outcome is selected" (Arthur, 2013, p. 1186). While the final level of stabilization cannot be predicted at the time of the launch, the dynamics that lead to the stabilization can be described by an urn model or computer simulation of positive feedback. The economic argument behind these dynamics is the mechanism of increasing returns (Arthur, 1994). David (1997) documented the consistency of the key placement from the early typewriters to modern computers. Even on smartphones the letters are placed in the same order on a "keyboard", if that wording is still appropriate, despite the fact that former reasons of optimization such as to prevent clashing or jamming of keys are not applicable anymore. Since the early days of path dependence theory many scientists have followed up on trying to extract or describe mechanisms that shape or stabilize a path-dependent process, discussing which cases can really be called path-dependent or whether they are just the outcome of utility optimized behavior and whether or not these are contradictions (Beyer, 2015; Liebowitz & Margolis, 2014). Similarly important is the debate on critical junctions, the beginning of paths or the very moment when the lock-in occurs (Collier & Collier, 1991; Sydow et al., 2009), and path creation, which tackles the questions whether a path can deliberately be created or altered (Garud & Karnøe, 2001). Nobel laureate Douglass North describes the effect of path dependence on decision-making in his book on institutions as follows: "At every step along the way there were choices — political and economic — that provided real alternatives. Path dependence is a way to narrow conceptually the choice set and link decision making through time. It is not a story of inevitability in which the past neatly predicts the future" (North, 1990, pp. 98-99). Even though behavior cannot be predicted as long as agents have the freedom to choose differently, a good estimation may be possible by assessments of the manner in which path dependency narrows the choice set or even channels decisions or actions when asymptotically approaching a lock-in. Can path-dependent behavior be locally approximated close to a lock-in? This is the overarching research question that will be answered in this paper using the specifically designed *SHE-Model*.

The definition of path dependence used in this paper goes back to the early path dependence theory (Sydow et al., 2009):

A *path-dependent process*
is a *self-reinforcing* process
with the tendency towards
a *lock-in*.

Thus, taking a mathematical perspective: What conclusions can be logically developed from the assumption of existing path dependence following the above definition? Can social behavior be locally approximated with the *SHE-Model*?

In the next sections the *SHE-Model* is presented and applied to simulate and assess potential opinion dynamics in a group of ideal type path-dependent agents. Although it is a basic swarming and herding model, the *SHE-Model* is designed to have hardly any cyclical movement in the networks of agents during the simulations. And, if available, the swarming agents follow somebody who has had the correct opinion in the previous time step, based on the feedback of the social environment.

The *SHE-Model* is used to re-aggregate social dynamics from the micro level to the macro level in a chain of reasoning from which follows that the *SHE-Model* can be used to approximate real life behavior.

The structural outline of the paper is that in the next section the important chain of reasoning is presented and explained. Afterwards, the *SHE-Model* is described in detail. In the subsequent section the model is used to answer the remaining questions from the chain of reasoning and to analyze how the simulated dynamics change when setup variables are altered. In a conclusion the core results are summarized and an outlook is briefly sketched.

6.2 The chain of reasoning

$\exists$ path-dependent process $p : A_i \rightarrow p(A_i)$ with A_i agents.
Does a path-dependent process necessarily lead to swarming and herding dynamics such as those simulated by the SHE-Model?
Vice versa, is all swarming and herding behavior embedded in a path-dependent process?

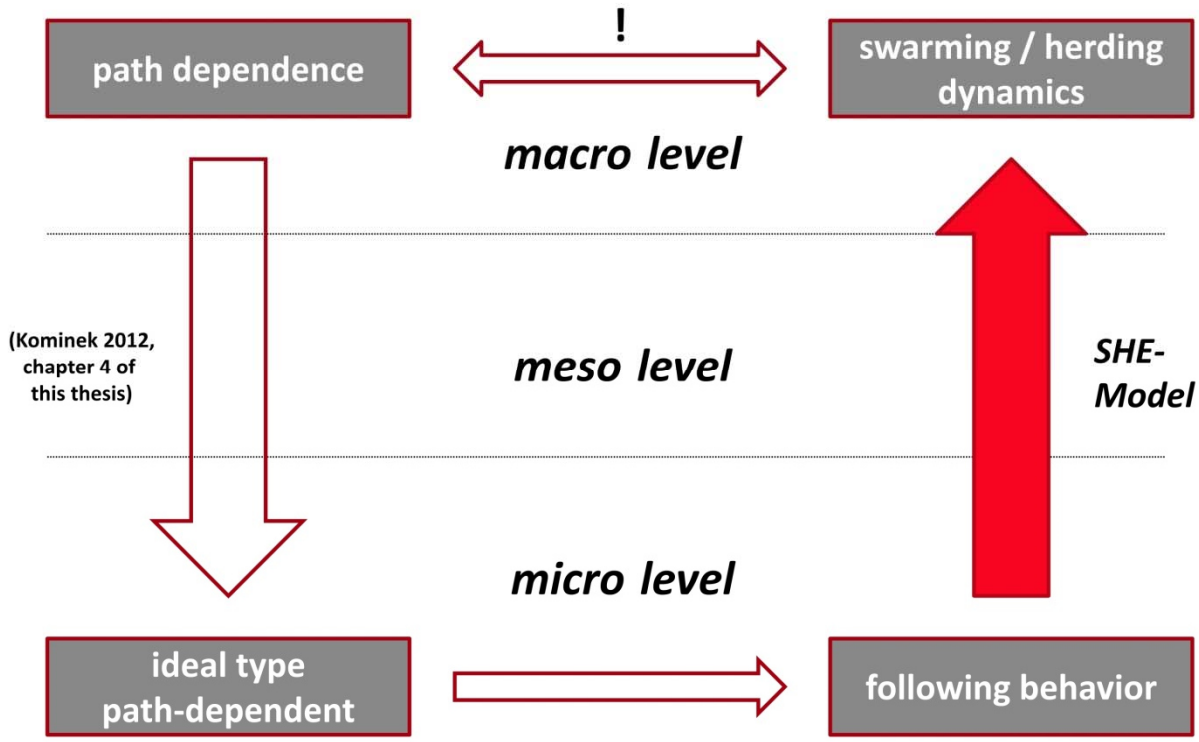

Figure 18 The chain of reasoning.
As soon as the "!" is proven, the *SHE-Model* can be used as a local approximation of path-dependent behavior, so the social dynamics that are simulated with the *SHE-Model* approximate real life behavior.

6.2.1 From the macro level to the micro level

The first deduction is from the macro level, on which path dependence theory is usually discussed, to the micro level, seeking to explain how a path-dependent process affects the behavior of involved or affected agents (Figure 18).

In this context, a key issue is how people behave when they are affected by path dependence. This question, which is addressed in detail in chapter 4 of this thesis, serves as a basis for the deduction of a theory of path dependence at the micro level: "Whatever it is that causes similar actions that can be understood as the following of a path, that way of acting becomes more and more of a habit" (see chapter 4). Applying the least-effort-principle (social psychology) a couple of times, which mainly states that the brain always takes the way of least effort to make decisions (e.g. Chaiken & Trope, 1999), Kominek deduces that the permanent shortcut in decision-making results in a following behavior of the considered agents who are affected by path dependence. This means that the more an actor tends to decide and act path-dependently, the more his decision-making processes tend to resemble ideal type path-dependent behavior (cf. chapter 4), which is to follow others such as neighbors or the masses, whatever is at stake in the given situation[17].

Thus, path dependency at the micro level can be described as following behavior. The more an agent decides and acts path-dependently, the more his behavior resembles an ideal type path-dependent, which implies to follow others.

6.2.2 Conclusions at the micro level

In the second step, the theory of the ideal type path-dependent is implemented as the basis of the *SHE-Model*. What happens in a group of agents of ideal type path-dependent? To allow a wide applicability of the *SHE-Model*, the implementation of the ideal type path-dependent has to be as plausible as possible. In general, following behavior of agents can either be the following of individual agents, the majority of all agents, or the majority of agents within a certain subgroup, the average of all agents, or the average of agents within a certain subgroup, or even external institutions or norms, whichever seem accessible for the agents to follow. These kinds of following behavior can be divided into two types, one swarming type for agents who obtain the information they follow directly locally within their vision, and a herding type for agents who follow some globally aggregated information. In the *SHE-Model*

[17] This theory of path dependence at the micro level (chapter 4) is deduced from the macro level definition of path dependence: A path-dependent process is a self-reinforcing process with the tendency for a lock-in (Sydow et al., 2009). This definition basically coincides with the more formalized definition by Vergne and Durand (2010) who "offer a narrow definition of path dependence as a property* of a stochastic* process which obtains under two conditions (contingency* and self-reinforcement*) and causes lock-in* in the absence of exogenous shock" (Vergne & Durand, 2010, p. 737).

the ideal type path-dependent agents are implemented as swarming or herding agents. While in each time step each swarming agent chooses one of its neighbors to follow for the opinion dynamics, a swarming agent moves in a flocking behavior such as aligning with others. Both are kinds of following behavior but over time the flocking behavior increases the likelihood of a swarming agent choosing to follow the same neighbor again and again, which supports the idea of path dependence. For the simulation of opinion dynamics herding agents are following the majority of all agents, i.e. the masses, while they move around in the average direction of all agents, which is herding. The idea behind this implementation is to start with a basic model, but still allow for a certain variety and interaction of at least two types of agents. Does the chain of reasoning already hold true for this basic model?

6.2.3 Back from the micro level to the macro level - the *SHE-Model*

Do the opinion or movement dynamics of a group of ideal type path-dependent agents always end up in a lock-in? Are multiple outcomes possible? During the simulations, the *SHE-Model* checks during each time step whether the group of agents already is in a lock-in and it stops as soon as the lock-in is reached. In the *SHE-Model* two types of lock-in are possible: an opinion-lock-in and a collective-movement-lock-in. It is even possible to have each type of lock-in separately or both reached at the same time step. Once the entire chain of reasoning holds true, this step becomes important because as soon as the "!" is proven, the *SHE-Model* can be used as a local approximation of path-dependent behavior so the social dynamics that are simulated with the *SHE-Model* approximate real life behavior.

6.2.4 Conclusions at the macro level

Does a path-dependent process necessarily lead to swarming or herding dynamics such as simulated by the *SHE-Model*? Or vice versa, is all swarming and herding behavior always embedded in a path-dependent process? Is all following behavior path-dependent? If the first, second, and third step of the chain of reasoning are all true, it follows that all path-dependent behavior can be described in swarming or herding dynamics as simulated by the *SHE-Model*. This chain of reasoning from the macro to the micro level and back to the macro level is also described by Coleman's boat. For the other direction of conclusions, the results of the *SHE-*

Model are important: if the opinion-dynamics are self-reinforcing with the tendency towards a lock-in they are path-dependent. If this holds true, then it can be concluded that for all following behavior that is simulated with the *SHE-Model* the opinion dynamics are path-dependent.

6.3 The *SHE-Model*

In the *SHE-Model* (Model of **S**warming and **H**erding agents affected by an **E**nvironment) a group of agents of the ideal type path-dependent is simulated. Agents of the ideal type path-dependent are following others, e.g. their neighbors or the masses, with regard to opinion dynamics and movement. Thus, in the model, which is coded in NetLogo (Wilensky, 1999), there are two different types of agents in a given environment:

Swarming agents: A swarming agent copies the opinion of a neighbor, which is another agent within his vision. He prefers to choose an agent who has had a correct opinion in the previous time step. The swarming movement resembles flocking behavior.

```
to opinion-swarming
  find-swarm-neighbors
  ifelse any? swarm-neighbors with [size? = true]
    [ find-big-neighbor
      create-link-to nearest-neighbor
      set new-color [color] of nearest-neighbor ]
    [ if any? swarm-neighbors with [size? != false] [
      find-random-neighbor
      create-link-to nearest-neighbor
      set new-color [color] of nearest-neighbor ]
    ]
end

to swarming  ;; turtle procedure
  find-swarm-neighbors
  if any? swarm-neighbors [
    find-nearest-neighbor
    ifelse distance nearest-neighbor < minimum-separation
```

```
      [ separate ]
      [ align ]
  ]
end
```

Herding agents: A herding agent follows the masses. Thus, his opinion corresponds to the majority opinion of all other agents. The herding agent copies the average heading of the entire group for his movement.

```
to opinion-herding
  if count (turtles with [color = blue ]) > count ( turtles with
      [color = yellow] ) [
          ask cows [ set color blue ]
        ]
  if count (turtles with [color = blue ]) < count ( turtles with
      [color = yellow] ) [
          ask cows [ set color yellow ]
        ]
  if count (turtles with [color = blue ]) = count ( turtles with
      [color = yellow] ) [
          ask cows [ ifelse random 2 = 0 [ set color yellow ]
            [ set color blue ]]
        ]
end

to herding  ;; turtle procedure
  find-swarm-neighbors
  if any? swarm-neighbors [
    find-nearest-neighbor
    ifelse distance nearest-neighbor < minimum-separation
      [ separate ]
      [ align-group ]
  ]
end
```

Environment: The environment gives feedback on which opinion is correct and can be changed randomly or manually.

```
to check-environment
  if environment = "Yellow is good" [
    set environmental 0  ; true means, yellow is good,
                           yellow turtles will grow
  ]
  if environment = "Blue is good" [
    set environmental 1  ; false means, blue is good,
                           blue turtles will grow
  ]
  if environment = "Avoid a lock-in" [
    if count turtles with [color = blue] >
      (number-of-agents * 0.9 ) [set environmental 0]
    if count turtles with [color = yellow] >
      (number-of-agents * 0.9) [set environmental 1]
  ]
end
```

In the model setup the user can determine the total number of agents (population) and choose how many of the agents (percentage of the population) are herding agents and how many agents (percentage of the population) are of a particular color, e.g. yellow, which represents the opinion of those agents. Conversely, all non-herding agents are swarming agents and all non-yellow agents have a different color, e.g. blue.

6.3.1 Swarming

In the model setup the swarming agents are assigned the default shape (as birds) and randomly spread. When it is their turn to take action during the model simulation, each of them performs the following steps: The swarming agent looks for neighbors (other swarming or herding agents) within its vision. From these neighbors it selects one to point to and prefers a big one, which implies that this neighbor has been correct (feedback from the environment) during the previous time step. Then the swarming agent follows the one pointed to by copying the color of the selected neighbor. If there is no other agent within its vision, it maintains its previous color. When it receives feedback from the environment it grows if it has the correct color and it shrinks if it has the wrong color. When the movement button is switched on, the swarming agent moves according to the swarming dynamics, which are based on the flocking model from the NetLogo model library (Wilensky, 1998).

Why do swarming agents prefer to select a big neighbor?

Every agent points to exactly one of the other agent whom he follows during a given time step or if nobody is in his vision he follows himself and maintains the color of the previous time step. When in a group only consisting of swarming agents each points to one of its neighbors they create at least one cycle in the network, which can be proven by complete induction.[18] So it is not generally possible to rule out cycles in the *SHE-Model*. But to reduce the likelihood of local occurrences of cycles, in the simulations all swarming agents have a simple preference to locally choose a particular agent, if available. And this particular agent is coded to be a big one, an agent who had the correct opinion in the previous time step. This implementation increases the likelihood of an adaptive behavior in the simulations.

6.3.2 Herding

In the model setup herding agents are shaped as cows and randomly distributed in the NetLogo world. During the model run, when it is their turn to take action each of them performs the following steps: The herding agent evaluates which color is predominant among all other agents (all herding and swarming agents). Then the herding agent follows the masses by taking on that dominant color. When the feedback from the environment is received, the herding agent grows if he has the correct color and shrinks if he has the wrong color. When the movement button is switched on, the herding agent turns towards the average heading of all other agents (swarming and herding ones) and moves in that direction.

6.3.3 Environment

The environment is determined by the user through a button. The user can choose between three alternatives: either yellow or blue is set to be “good”, i.e. the correct opinion, or the feedback is generated to “avoid a lock-in”, trying to avoid an opinion-lock-in at each time step. The setup allows for a manual change by the user through the interface between time

[18] If there is at least one non-swarming agent in the *SHE-Model* that consequently is a herding agent and cycles are excluded, all swarming agents follow that one non-swarming agent, which can be proven by complete induction, too.

steps. Also, the feedback can be evoked after changing the environment option on the interface. The environment provides feedback on the decisions the agents have taken so the agents with the correct opinion grow and the others shrink. The environment itself is not visualized in the *SHE-Model* simulations. The environment only feeds back on the opinions (colors) the agents have, so they either have the right opinion – then they grow – or they have the wrong opinion – then they shrink in size.

Why "avoid a lock-in"?

When movement is switched on and herding is less than 50%, the swarming dynamics are so efficient in spreading the opinion favored by the environment that a collective-movement-lock-in is very rare. It only occurs in 2.5% of the runs and only 0.03% of the runs with vision 5. Therefore, I have created the chance of switching the environment to "avoid a lock-in", which implements the idea of trying to avoid an opinion-lock-in to allow in the simulations to reach a collective-movement-lock-in to analyze the swarming/herding dynamics more thoroughly. Consequently, when the "avoid a lock-in" option is selected for the environment on the interface, in the simulation the environment switches from "yellow is good" to "blue is good" when there are less than 10% of the population of agents left whose color is blue. That way a new round of opinion adaptation starts, trying to avoid the opinion-lock-in. The limit of 10% is arbitrary but set up as a constant in the code[19].

6.4 Simulations and Results

A few questions from the previous section still need to be answered:

- Do the actions of a group of ideal type path-dependent agents always end up in a lock-in? Are multiple outcomes possible (when aggregating from the micro level to the macro level)?

[19] When analyzing the simulation results it can be concluded that for some visions the level of 10% is sufficient, for some it is too large and for others too small. E.g., for vision 5 it still happens very often that because of the larger radius of agents within vision an agent of the preferred color can be spotted by a larger group of agents who then all adapt to that opinion in the same time step. Thus, they can be more than 10% of the population and still produce an opinion-lock-in, exceeding the limit for an environmental change in the setting of "avoid a lock-in".

- Are the opinion-dynamics self-reinforcing with the tendency towards a lock-in, thus, path-dependent (for the final conclusion on the macro level)?
- Finally if the chain of conclusion is proven: On which model variables do the social dynamics simulated with the *SHE-Model* depend in which way (to obtain information on potential real life behavior)?

To assess whether the actions of a group of ideal type path-dependent agents always ends up in a lock-in in the simulations, all combinations of relevant variables need to be simulated in the NetLogo BehaviorSpace and it has to be noted if a lock-in occurs and which kind it is or if both lock-ins are reached at the same time step. An interesting feature of path dependence that is mentioned in the literature is that in the beginning of a process the final level of the lock-in cannot be predicted, i.e. multiple outcomes are possible and the process is not entirely deterministic (Arthur, 1994; Vergne & Durand, 2010). To measure this chance for multiple outcomes in the model simulations at the state of the lock-in at the end of the simulation the final number of yellow agents is counted. The standard deviation can then show how strongly this final number of yellow agents then depends on the random spread of the agents at the beginning of the simulation.

To assess whether or not the simulated opinion dynamics are path-dependent, in addition to monitoring the lock-ins, the dynamics along the way of reaching the lock-in need to be measured. Therefore, the number of steps until lock-in is counted and analyzed. The simulations are started with only one yellow agent, so then the opinion diffusion can be assessed by counting the number of steps until lock-in and noting the final number of yellow agents. If even in a changing environment always the correct opinion diffuses it can be concluded that the dynamics are self-reinforcing.

Finally, for real life applications it is interesting to obtain more information about the interdependencies of variables used for designing the simulated dynamics in the *SHE-Model*. Which variables affect the social dynamics in which way?

6.4.1 What happens when a group of ideal type path-dependent agents interacts?

This is the fundamental question of the *SHE-Model*. Following each other or the masses, the agents of the ideal type path-dependent can move around in a swarming or herding behavior and adapt to opinions from others. There are two basic dynamics that can occur in the simulations of the *SHE-Model*: Opinion dynamics that are marked by the colors and movements. While movements affect opinion dynamics, opinion dynamics do not affect movements (Table 3). And while the environment only affects the opinion dynamics, e.g. the vision affects both opinion dynamics and movements.

When running the *SHE-Model*, first the setup creates the number of agents according to the pre-defined ratio of swarming and herding agents and spreads them randomly in the world. Also the initial heading of the agents is random. The agents are colored based on the pre-defined percentage of yellow agents. Then the ideal type path-dependent agents are ready for the go-procedure.

variables on the user interface	opinion dynamics	movement	in the simulations
number-of-agents	has an effect	has an effect	100
percentage of herding agents	has an effect	has an effect	0-100
percentage of yellow agents	has an effect	no effect	1
environment	has an effect	no effect	yellow is good, avoid a lock-in
vision	has an effect	no effect	3-5
movement	has an effect	has an effect	none, swarming and herding
show-links	no effect	no effect	off
minimum-separation	has an effect	has an effect	1
max-align-turn	has an effect	has an effect	13.75
max-cohere-turn	has an effect	has an effect	5.5
max-separate-turn	has an effect	has an effect	1.5

Table 3 Variables in the user interface, their effect on the opinion dynamics or movements and how they are set or changed throughout the simulations in the BehaviorSpace of NetLogo.

To assess the movement and opinion dynamics that can evolve in a group of path-dependent agents from a social simulation perspective, it is particularly interesting to vary the combination of agents and thus the percentage of herding versus swarming agents (Table 4) as well as the percentage of yellow versus blue agents. At which constellation do significant effects occur?

Furthermore, to analyze the number of steps it takes until the population reaches a lock-in it is important to know how quickly a preferred opinion spreads throughout the population. Therefore, the agent's vision (Table 4) is an important variable to vary in order to check the dependence on single agent's characteristics versus the effects of initial group constellations such as the percentage of herding agents.

Especially when analyzing the dynamics that lead to a collective-movement-lock-in, it helps to be able to change the environment variable during the run of a simulation to avoid an opinion-lock-in prior to the collective-movement-lock-in.

To focus on these variables in the assessment of path-dependent processes, the other four variables shaping the movement, which are minimum-separation, max-align-turn, max-cohere-turn, and max-separate-turn, are held constant. Therefore, simulations are performed for the following combinations of variables:

1000 individual simulation runs are performed for each combination, so there are 1515000 runs in total (Table 4). During the runs the number of steps until the lock-in is recorded as well as the type of the lock-in, and the final number of yellow agents at the moment when the lock-in is reached (results can be found in Figure 19, Figure 20, and Figure 22 through Figure 24). Afterwards the standard deviations of the number of steps until lock-in and of the final number of yellow agents are also calculated. The standard deviation is used for inferences on the relevance of the random spread at the beginning of each run and thus of the relative starting positions of the agents.

		no movement					**with movement**					**with movement "avoid a lock-in"**			
		vision					**vision**					**vision**			
		3	3.5	...	5		3	3.5	...	5		3	3.5	...	5
percentage of herding agents	0														
	1														
	...														
	100														

Table 4 The *SHE-Model* is run using the BehaviorSpace of NetLogo with 1000 runs for each of the combinations denominated in this table.

6.4.2 What are the key findings?

In the situation of the opinion-lock-in either all agents have the same color or there are agents who cannot reach out to adapt to the environment anymore. Therefore, there are a number of agents of one color left that cannot change anymore (cf. e.g. Figure 21). In the situation of a collective-movement-lock-in all agents have the same heading so they move collectively in the same direction and their positions relative to each other do not change anymore. If a collective-movement-lock-in occurs there could also be an opinion-lock-in in the cases, when the number of agents of one color does not change anymore. But a collective-movement-lock-in can also happen without an opinion-lock-in if the number of agents of one color changes periodically within a frequently changing environment.

Without movement in the simulations there is always an opinion-lock-in and no collective-movement-lock-in (Figure 19). The latter is very improbable because the headings of the agents do not change and a collective-movement-lock-in in the case of no movement implies that all agents have the same heading from the very beginning, which is extremely unlikely for 100 agents with randomly set up headings. With movement, the collective-movement-lock-in still occurs rather seldom (Figure 20, left): for shares of herding agents below 40% there is hardly ever a collective-movement-lock-in. For larger shares of herding agents the collective-movement-lock-in occurs more often, with a maximum for 50% herding agents,

when almost always a collective-movement-lock-in occurs (Figure 20, middle left). For even larger shares of herding agents a collective-movement-lock-in occurs with a decreasing tendency. The reason is that the very step when in a simulation with a share of 50% herding agents the masses change their mind, the group already reaches an opinion-lock-in. With movement switched on and the herding agents set up randomly in the world, the swarming agents are likely to follow herding agents. Partly clustered in swarms the swarming agents locally approach the heading of the herding agents while the herding agents only change their headings in tiny nuances as long as the swarming agents differ. For shares of herding agents that are larger than 50% the herding agents never change their opinion but with the masses heading in one direction anyway a collective-movement-lock-in can be approached sometimes even more quickly than an opinion-lock-in (Figure 20, left). Only for shares of herding agents between 60% and 90%, there is a chance for a collective-movement-lock-in without an opinion-lock-in, which occurs up to about 20 times in 1000 simulations (Figure 20, top left).

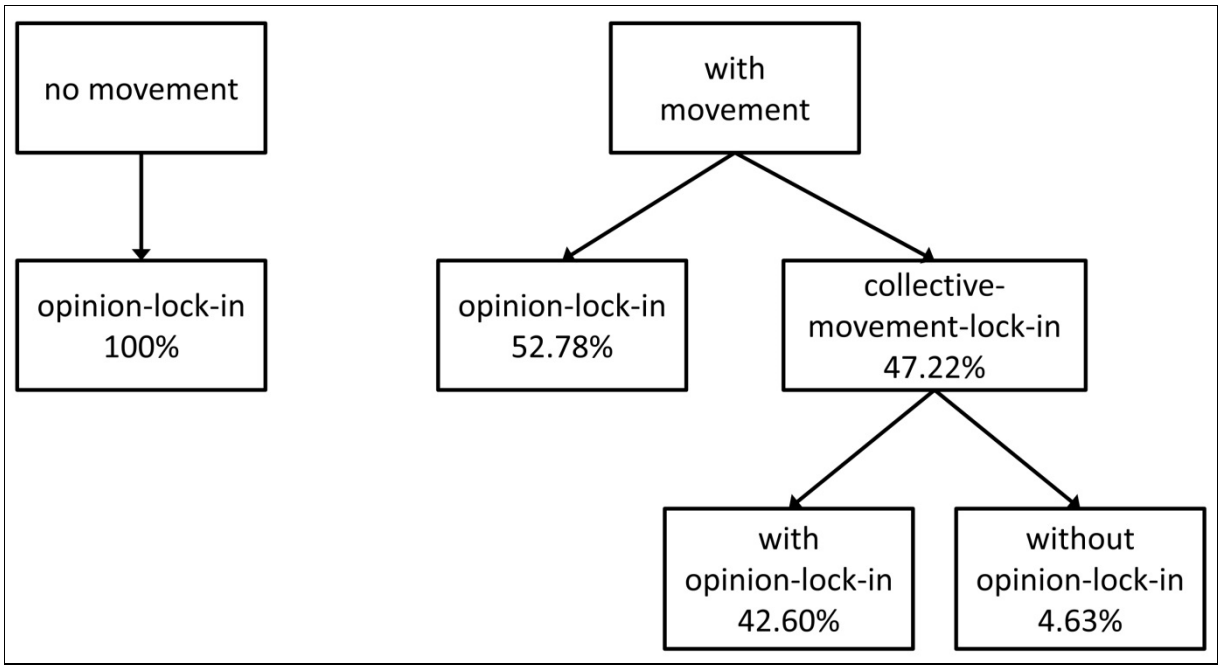

Figure 19 Overview of potential lock-ins in situations of no movement or with movement including the case with movement and the environmental setting of “avoid-a-lock-in”.

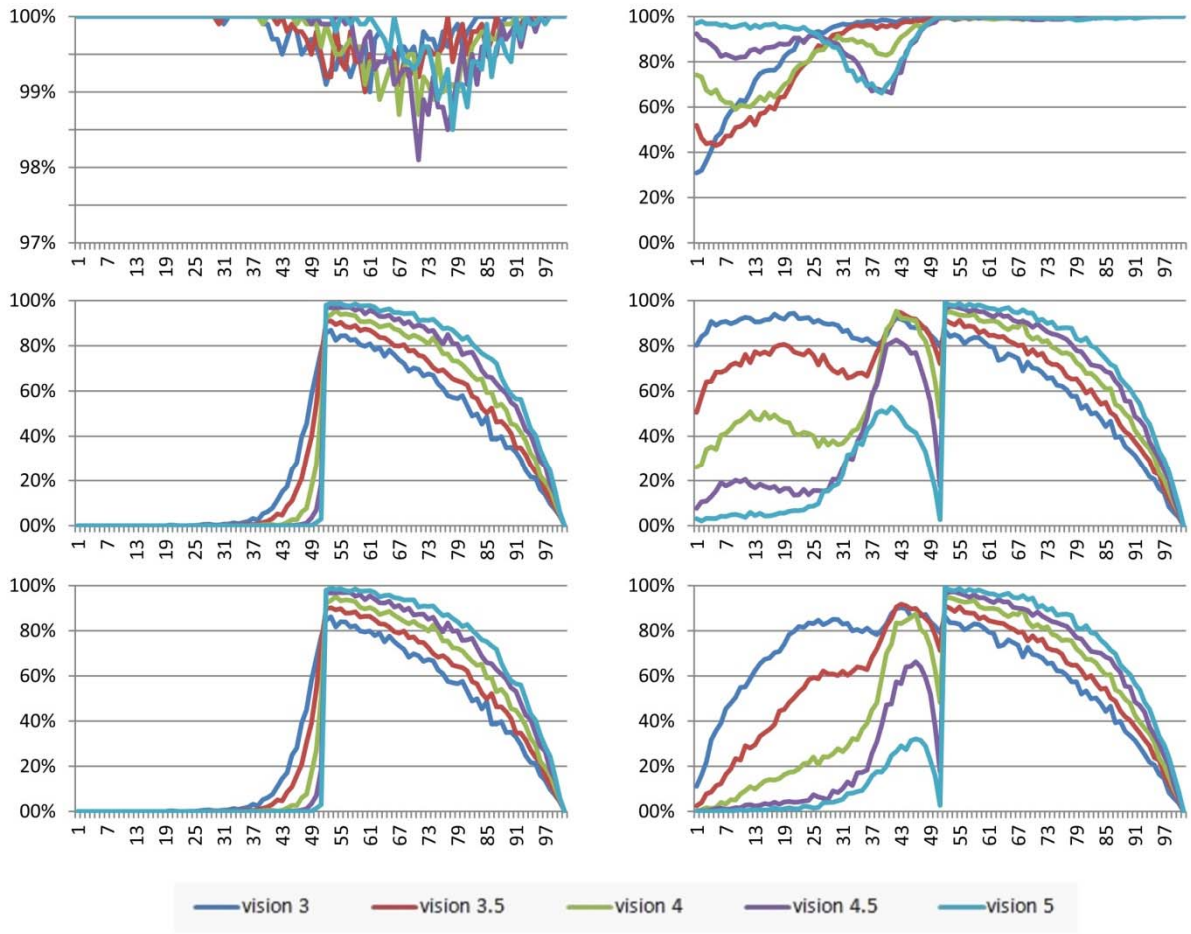

Figure 20 Number of the runs of the *SHE-Model* with movement that result in an opinion-lock-in (top), in a collective-movement-lock-in (middle), or in both at the same time (bottom) plotted in dependence on the share of herding agents (x-axis).
On the left, the *SHE-Model* is run without avoiding a lock-in; on the right, the environmental setting is "avoid a lock-in".

6.4.2.1 No movement

When running the *SHE-Model* in a set environment an opinion-lock-in occurs quickly if there is no movement (Figure 22, left). In the situation of the lock-in either all agents have the same color or there are agents who cannot reach out to adapt to the environment anymore. Consequently, the number of agents of one color can no longer change (Figure 21).

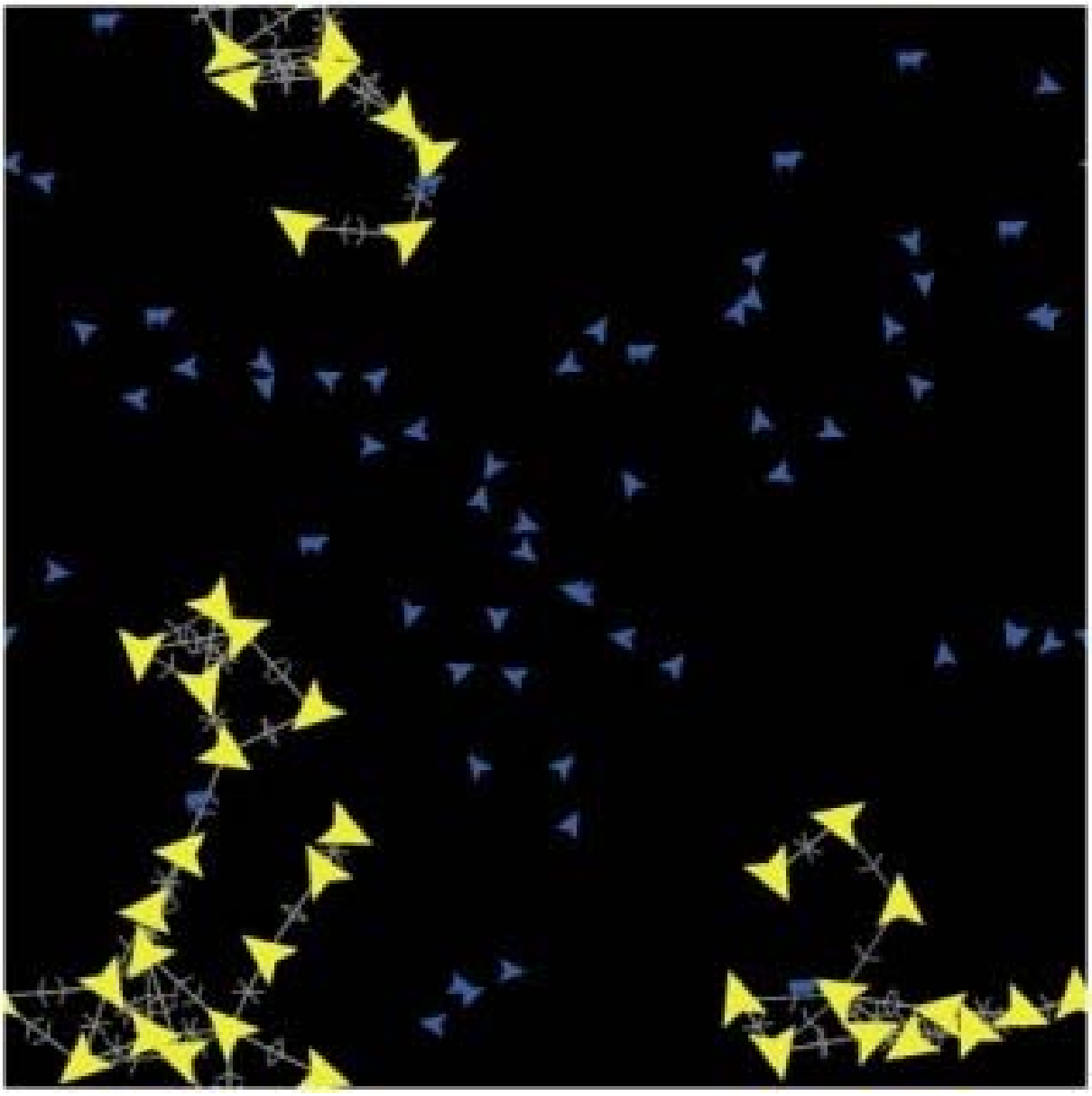

Figure 21 Example of an opinion-lock-in without all agents having the same color.
Screenshot of the model world after 11 ticks when the opinion-lock-in is reached with a final number of 38 yellow agents and without a collective-movement-lock-in. The initial values have been: number of agents: 100, percentage herding: 10%, percentage yellow: 1%, environment: "yellow is good", vision: 3.5, movement: none, show-links: on, minimum separation: 1, max. align turn: 13.75, max-cohere-turn: 5.5, max-separate-turn: 1.5.

A clear trend can be observed: the higher the percentage of herding agents, the lower the average number of steps until lock-in. However, for visions of 4.5 and 5 at first a slight increase in steps until lock-in occurs up to about a share of 35% or 45% herding agents (Figure 22, top left).

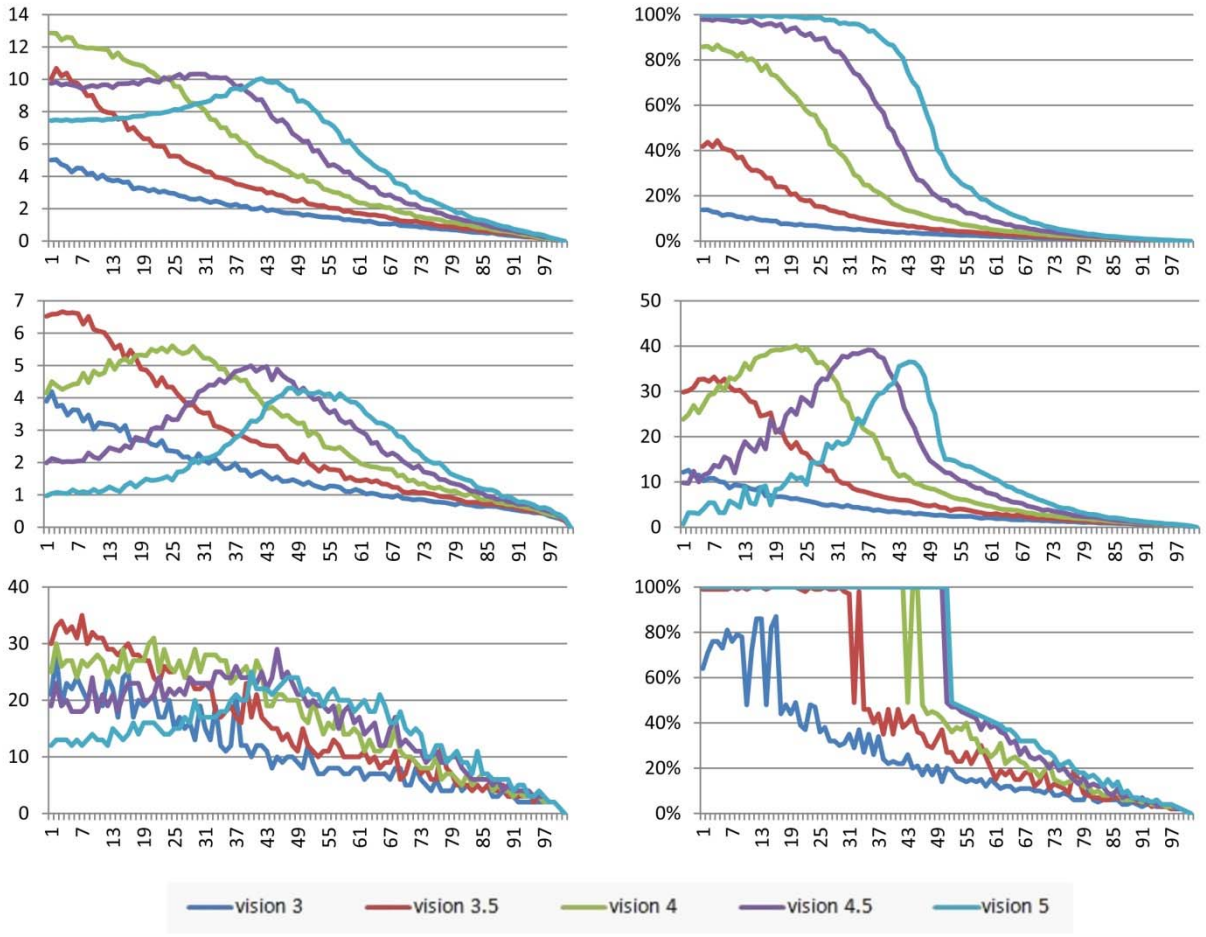

Figure 22 Results of the runs of the *SHE-Model* without movement plotted in dependence on the share of herding agents (x-axis), averaged over 1000 runs for each combination.
On the left: average steps till lock-in (top), average standard deviation for steps till lock-in (middle), maximum steps till lock-in (bottom); on the right: average number of final yellow agents (top), average standard deviation of the number of final yellow agents (middle), maximum number of final yellow agents (bottom).

The reason is that for visions of 4.5 and 5 nearly all agents are reached if the percentages of herding agents are low because swarming is very efficient for large visions. Thus, for low percentages of herding agents they rather obstruct the swarming agents (especially locally) because they do not adapt to changes in the environment like the swarming agents. When the average of the final number of agents with a correct opinion decreases (significantly) (Figure 22, top right), the average number of steps until lock-in also decreases (with increasing percentage of herding) (Figure 22, top left) because on average fewer steps are needed to reach fewer agents.

The number of steps until lock-in significantly depends upon the spread of agents in the world (Figure 22, middle left). For visions 3 and 3.5 the standard deviation for the average number of steps until lock-in is largest for small shares of herding agents. In that case the herding agents even have a positive effect on the number of steps because for small visions herding agents can help to reach remote regions and a larger spread more promptly (Figure 22, top left). If not all agents are reached despite larger numbers of herding agents (Figure 22, top right) it is likely that either single agents are too distinct and far away, which depends on the spread of agents in the setup and is documented by the standard deviation (Figure 22, middle right), or not even all herding agents are reached, which implies that less than half of the agents are finally reached (yellow) (Figure 22, top and bottom right). In the latter case the herding agents can practically block swarming agents and prevent their contact with other yellow agents, diminishing their ability to adapt. Especially if the share of herding agents is close to but still below 50%, the herding agents can block the swarming agents or significantly increase the distance they have to cover before getting in touch with other swarming agents because they have to find their way around the herding agents. If the share of herding agents is larger than 50% they definitely do not adapt to a changing environment themselves in any case (Figure 22, bottom left). And a large share of herding agents can effectively disconnect and thereby prevent some of the swarming agents from adapting. Thus, the total number of agents that is potentially able to adapt is smaller than the initial group size. Furthermore, they reach a lock-in more quickly, which is particularly the case for large shares of herding agents (Figure 22, bottom right).

The maximum number of steps until lock-in depends significantly on the spread of agents in the world (Figure 22, middle left). The maximum number of agents reached significantly depends on the percentage of herding agents and the extent of vision of each agent (Figure 22, bottom right).

6.4.2.2 With movement – swarming and herding in a “yellow is good” environment

If movement is switched on in simulations that are comparable to the experiments without movement, the opinion-lock-in is more likely to reach all agents (cf. Figure 22 and Figure 23,

top and bottom right), and in cases of a share of herding agents larger than 50% at least all swarming agents. However, this does not have to be quicker (cf. Figure 22 and Figure 23, top and bottom left) because more agents need to be reached and the movement clustered in swarms could prevent groups of agents to actually meet the agents of the environmentally preferred opinion.

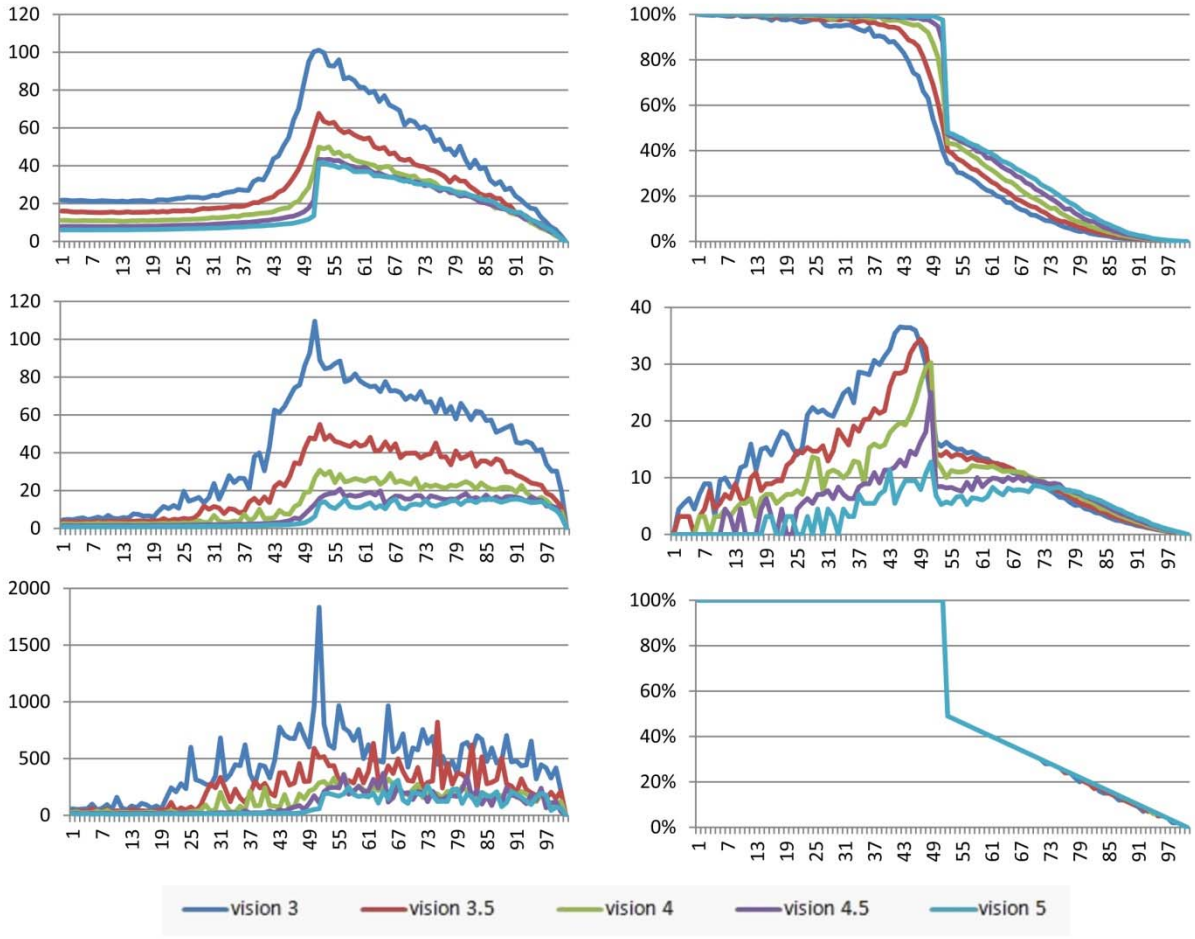

Figure 23 Results of the runs of the *SHE-Model* with movement but without avoiding a lock-in plotted in dependence on the share of herding agents (x-axis), averaged over 1000 runs for each combination.
On the left: average steps till lock-in (top), average standard deviation for steps till lock-in (middle), maximum steps till lock-in (bottom); on the right: average number of final yellow agents (top), average standard deviation of the number of final yellow agents (middle), maximum number of final yellow agents (bottom).

Theoretically, even with movement in a fixed environment there are cases possible with a low density and a relatively small vision that leads to an opinion-lock-in without all agents having

the same color or where it takes very long until the color is finally spread completely: For example, let there be a population of two swarming agents of different colors with different headings (if they had the same heading, they would be in a collective-movement-lock-in, which is considered later on). Then depending on the starting distance between the agents, their velocity, and the angle between the lines of their movement, it might take very long until they meet. There may also be cases, in which they never meet because they move periodically. If they meet they adapt to the preferred color resulting in an opinion-lock-in of all having the same color. If they never meet, the result is an opinion-lock-in with different colors.

But if the population is large enough and the density is sufficient for the swarming and herding mechanisms to be effective, the movement leads to quicker lock-ins and in the state of the lock-in all agents have the same color.

6.4.2.3 Movement without avoiding a lock-in

Both the average number of steps (Figure 23, top left) and the average number of finally reached (yellow) agents (Figure 23, top right) significantly depend upon the percentage of herding agents. Especially, the maximum number of finally reached (yellow) agents does not depend on the vision anymore at all but only on the share of herding agents (Figure 23, top right). The standard deviation of the average number of finally reached (yellow) agents (Figure 23, middle right) depends upon the vision but only if the share of herding agents is lower than 50%. Considering the average or maximum number of steps until lock-in (Figure 23, middle and bottom left), these are clearly affected by the vision: more steps are needed for smaller visions and fewer steps for larger visions, showing a higher level for shares of herding agents that are larger than 50%.

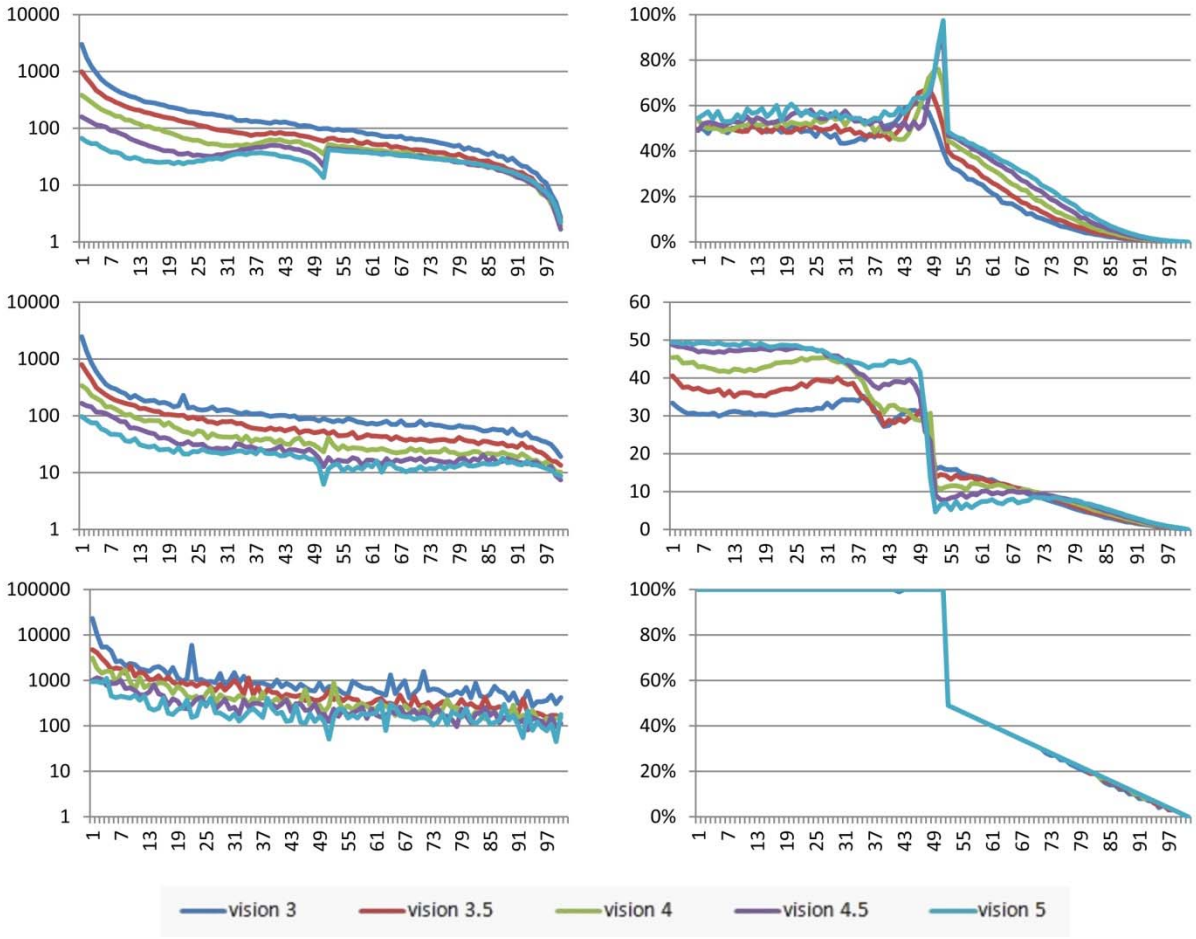

Figure 24 Results of the runs of the *SHE-Model* with movement and in the "avoid a lock-in" environment plotted in dependence on the share of herding agents (x-axis), averaged over 1000 runs for each combination.
On the left in a logarithmic scale: average steps till lock-in (top), average standard deviation for steps till lock-in (middle), maximum steps till lock-in (bottom); on the right: average number of final yellow agents (top), average standard deviation of the number of final yellow agents (middle), maximum number of final yellow agents (bottom).

6.4.2.4 Movement, swarming and herding while avoiding a lock-in

In case of swarming and herding in an "avoid a lock-in" environment the vision hardly matters (Figure 24) despite the fact that for a vision larger or equal to 4 the logarithm of the average number of steps shows a significant change in behavior at a share of herding agents of 50% (Figure 24, top left). For a percentage of herding agents smaller than 50%, the average share of finally yellow agents is around 50% for all visions, which is half of the total population size (Figure 24, top right). This is not a surprise because throughout the simulation the environment can change and it is random which color finally is environmentally preferred when the lock-in occurs. But there is a clear maximum for the average final number of yellow

agents for each vision. This maximum is higher and more pronounced the larger the vision is. Furthermore, to reach that maximum a larger share of herding agents is necessary for larger visions, approaching 50% from below. This is due to the fact that the closer the share of herding agents gets to 50% the more likely it is that the entire population enters the lock-in during the very step, in which the herding agents change their mind. And because of the setup rule for the environment to switch to the other color as preferred one whenever there are less than 10% of the agents of that color left, the environment does not change but the population rather locks-in with the preset environment, which is "yellow is good", for a share of herding agents that is close to 50%. The same argument about the environment holds for shares of herding agents that are larger than 50%. Therefore, the graphs for those cases do not differ from the ones with movement without avoiding a lock-in (cf. Figure 23 and Figure 24).

The standard deviation for the average number of final yellow agents is larger for shares of herding agents that are smaller than 50% than for shares that are larger than 50% (Figure 24, middle right). And it increases the larger the vision becomes. The latter is especially interesting because for movement without avoiding a lock-in this correlation is the opposite way: it increases the smaller the vision becomes (Figure 23, middle right). The explanation is that in the setting of "avoid a lock-in" the environmental preference for yellow or blue changes. And for shares of herding agents that are smaller than 50% the environment changes frequently from "yellow is good" to "blue is good" and back. It is more likely that not all agents are finally reached in the final environment right before the lock-in for a smaller vision than for a larger vision, comparable to the other simulations with movement and without a changing environment. But "all agents reached" can differ between zero, which corresponds to the case that all agents are finally yellow in a "blue is good" environment, and 100, which represents the case that all agents are finally yellow in a "yellow is good" environment. Therefore, the spread of results and thus their associated standard deviation is larger for larger visions and smaller for smaller visions (Figure 24, middle right).

6.4.3 Implications for the chain of reasoning

6.4.3.1 Is a lock-in always reached? Are multiple outcomes possible with regard to the final share of colors?

In the *SHE-Model* there are two components that can cause a global lock-in: The opinion dynamics (colors) and the structure (spatially explicit representation of a network or collective movement). The lock-in is defined as the inability to adapt to a changing environment. Considering the opinion dynamics, in the *SHE-Model* simulations the ideal type path-dependent agents reach a lock-in when all agents have the same opinion. Or a lock-in can already be reached through structural effects in the spatially explicit network representation or collective movement if in all discrete parts of the model world all agents locally share the same opinion. In the model simulations run with the *SHE-Model* and analyzed in the previous section a lock-in has always occurred (Figure 19 and Figure 20).

A non-moving spatially explicit representation of a network is structurally inflexible. Depending on the distance of swarming agents and their vision it can happen that there are parts of the network that are blue and others are yellow and there is no way that each of the parts can adapt to the other (Figure 21). In a moving network this particular situation seems less likely but still there are simulations of the *SHE-Model*, in which opinion dynamics are limited because all agents move in the same direction in one collective movement and the distances between them remain constant (Figure 20, middle). So there are even cases of collective movement, in which colors may be locally different from the rest of the world but they are unable to spread out when the collective-movement-lock-in is reached (Figure 20, bottom). Therefore, they cannot adapt to a changing environment anymore and also an opinion-lock-in is reached concurrently.

In the setup of the *SHE-Model* all agents are distributed randomly. And also their heading is initially random. Consequently, just based on the ratio of herding to swarming agents or the initial number of yellow or blue agents it cannot be predicted at which ratio of blue to yellow the agents will lock-in or in which direction the population is finally heading when the lock-in is reached via the collective movement. This guarantees the possibility of multiple outcomes.

6.4.3.2 Are the opinion dynamics simulated with the *SHE-Model* path-dependent?

To answer this question, in addition to the previously analyzed tendency towards a lock-in it needs to be assessed whether or not the opinion dynamics are self-reinforcing. Well, they are: If there are more than 50% herding agents in the population, the masses consisting of the herding agents reinforces the predominant color. If there are less than 50% herding agents in the population, the environment enforces the correct color. Swarming agents spread the correct color within their reach and thus reinforce the color via the hierarchical structure of the bottom-up network. The spatial hierarchical structure has the effect that the larger the group of agents of the correct color is, the higher the probability becomes for the rest of the agents to adapt to that color. The lock-in can occur before all agents are reached as described above. But nevertheless, before the lock-in the opinion dynamics are self-reinforcing.

Therefore, the path dependence experiment using the *SHE-Model* is comparable to the path dependence experiments by Arthur (1994). This is important because this proves that the definition of path dependence at the micro level is a coherent extension of the concept of path dependence at the macro level (concept by e.g. Arthur, 1994; David, 2001).

6.5 Conclusion

The *SHE-Model* presented in this paper can be used as a local approximation of path-dependent behavior, so the social dynamics that are simulated with the *SHE-Model* approximate real life behavior. This is deduced in a chain of reasoning for opinion dynamics simulated with the *SHE-Model*. Starting with a definition of a path-dependent process, in this paper it is assumed that path-dependent processes exist. On this basis a former deduction (chapter 4 of this thesis) is used to deduce an ideal type path-dependent who basically performs following behavior. Therefore, where people in real life are affected by a path-dependent process, their behavior is shaped in a way that they tend to follow others. This following behavior is implemented in the *SHE-Model* to assess what dynamics can evolve from this kind of behavior to address the question: What is the implication of path-dependent processes on opinion dynamics in real life?

For opinion dynamics the chain of reasoning can be completed from the macro to the micro level and back to the macro level including the *SHE-Model* for aggregation. And for opinion dynamics even the opposite direction of conclusion holds true, which implies that the dynamics simulated with the *SHE-Model* can be used as local approximation for path-dependent processes that are in or close to a lock-in. This reveals great chances for real life application even though the *SHE-Model* presented in this paper is only a basic model: Swarming and herding behavior consist of very simple rules. But this is also the strength of the model that even these basic rules lead to a model that fulfills the chain of reasoning that allows the use of the model as an approximation.

In the future the *SHE-Model* can be fine-tuned to improve the approximation of real life behavior while at each step of changing the model one needs to check whether the chain of reasoning still holds true to prove its real life applicability. And in case studies applications of the *SHE-Model* can assess how precise an approximation of real life behavior already is using this basic model. This may reveal in which direction further fine tuning is necessary.

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7 Each institutionalization elementary is a self-reinforcing process increasing path dependency

Jasmin Kominek

This chapter is submitted for publication.

Abstract

Institutionalism and the concept of path dependency are related theories. Thus, in empirical research it is necessary to know which of the two theories is applicable. In this paper, it is proven in a mathematical way that whenever institutionalism can be used, the concept of path dependency can be applied as well. Based on Berger and Luckmann's theory of primary and secondary socialization and Giddens' theory of the duality of structure, it is shown that each institutionalization elementary is a self-reinforcing process increasing path dependency. As a corollary, a theoretical basis is provided for 'intertheoretical' work using the presented linkage between institutionalism and path dependency theory, as well as for a multi-level approach using path dependency theory.

Keywords

institutionalism, path dependency theory, multi-level approach, socialization, duality of structure, linkage between theories

7.1 Introduction

One of the main problems, when trying to apply path dependency theory in empirical research, is the question whether a process indeed is path-dependent or not. So a classification of the assessed process is needed and a theoretical background is necessary to fit the empirical

situation to an underlying theoretical concept. Two related theories are institutionalism and the concept of path dependency. To cluster empirically monitored processes it may be necessary to distinguish whether a process is an institutionalization and thus institutionalism should be used, or whether it is path-dependent and thus the concept of path dependency can be applied.

In this paper it will be shown that each institutionalization elementary is a self-reinforcing process, which implies that whenever institutionalism can be used the concept of path dependency can be applied as well. To prove this statement, first a definition of 'path dependency' will be deduced from literature. While the most important aspect of the general understanding of path dependency is that 'history matters', more specific applications, particularly related to organizational theory, use the definition of a path dependent process being a 'self-reinforcing process with the potential for a lock-in'. The latter definition opens up a possible linkage to institutionalism because a lock-in is comparable to the situation of an institution that changes only incrementally at most (North, 1990). In contrast to other authors who combine path dependency and institutionalism (e.g. Alexander, 2001; Pierson, 2000), a more process-oriented definition of institution is used in this chapter: Each institution is the result of a process of institutionalization. This definition allows the focus on the institutionalization part of the theory. Considering the process of institutionalization, there must be at least one actor who supports the process of institutionalization, which means that the foundation of the future institution must already exist in his subjective reality. This is how the 'elementary' view of the process of institutionalization is defined.

Before proving the statement that each institutionalization elementary is a self-reinforcing process, the underlying theories are assessed based on existing scientific literature. A particular emphasis is placed on the concept of primary and secondary socialization (Berger & Luckmann, 1979) and the statement of the duality of structure (Giddens, 1984)[20]. Afterwards, the proof is presented and at the end a more dynamic understanding of path dependency is suggested. This allows the expansion of the applicability of path dependency theory and the

[20] To ascertain that both theories can be used together consistently, their basic concepts of habitualization (Berger & Luckmann, 1979) and routinization (Giddens, 1984) are also outlined in this context, as they are the basis for their understandings of institutionalization (Berger & Luckmann, 1979) and institutions (Giddens, 1984).

combination of institutionalism and the concept of path dependency in a consistent theoretical framework.

7.2 Definitions of Path Dependency and Institutions

7.2.1 Path Dependency

First, the concept of path dependency is presented. It is a prerequisite for the explanation of the causal logic between path dependency and self-reinforcing processes, which is key for understanding the main aspect of the statement that is subsequently proven (‘Each institutionalization elementary is a self-reinforcing process.’) and the implications that result from this statement.

7.2.1.1 The Story of QWERTY, an Example of the Phenomenon of Path Dependency

Although Liebowitz and Margolis (1995) still argue that the QWERTY-keyboard is not an example of the phenomenon of path dependency, it is strongly associated with David’s and Arthur’s work, on which the path dependency notation in the social sciences is based (cf. e.g. Beyer, 2005; Mahoney, 2000; Page, 2006; Sydow et al., 2005, 2009). Arthur and David criticize the efficiency requirements of neoclassical economics and point out that in a market not necessarily the most efficient technology prevails. While Arthur focuses on positive feedback processes of increasing returns and shows that they can lead to suboptimal technologies dominating the market (Arthur, 1989, 1994), David provides additional examples through historical research (David, 1985, 2001, 2007). A particularly famous example is the QWERTY-keyboard. The denomination of this keyboard is due to its topmost row of letters ‘QWERTYUIOP’.

In his historical research on the development of the typewriter, David points out that initially the keys have been placed in this particular order because in the early years of production, line salesmen were assumed to write the brand name, ‘Type Writer’, especially quickly if all of the

name's letters were placed in the top row (David, 1985). Thus, although the QWERTY-keyboard was designed to somehow meet the preferences of decision-makers in the past and their reasons might have become irrelevant in the meantime, the QWERTY-keyboard still dominates the keyboard market today, even though there are no longer type bars that need to be prevented from clashing or jamming, different brand names and no salesmen with the necessity to type the phrase 'type writer' particularly quickly. Even smartphones that do not even have 'keys' anymore, still use the same QWERTY-keyboard positioning of letters that is based on a patent from 1873.

> "The agents engaged in production and purchase decisions in today's keyboard market are not the prisoners of custom, conspiracy, or state control. But while they are, as we now say, perfectly "free to choose", their behavior, nevertheless, is held fast in the grip of events long forgotten and shaped by circumstances in which neither they nor their interests figured" (David, 1985, p. 333).

While the broader understanding describes path dependency as 'history matters', a more in-depth analysis focuses on that self-reinforcing processes that stabilize paths.

7.2.1.2 Path Dependency in a Narrower Understanding: Self-Reinforcing Processes

Using the example of the QWERTY-keyboard, David explains the lock-in of a path with the quasi irreversibility of investments (David, 1985). Even though it would be technically possible for a company producing keyboards to change the positioning of keys, users have to rely on their typing qualities whose experience in typing on the QWERTY-keyboard can be described as quasi irreversible investments. So the more the QWERTY-keyboards are sold and used in practice, the more users learn to type on them and the more companies prefer to buy QWERTY-keyboards for their employees in the future. The more QWERTY-keyboards are already used, the more they will be asked for and used in future.

Arthur formalizes this causality as a self-reinforcing process[21]. In the example of the QWERTY-keyboard, the 'self' that gets 'reinforced' may be the number of people preferring

[21] A 'self-reinforcing process' literally is a process, in which a 'self' gets 'reinforced'. For each application it has to be defined what the 'self' is that gets reinforced. For instance, the 'self' can be the number of involved

the QWERTY-keyboard instead of a potential alternative: Whenever the QWERTY-keyboard is preferred, it reinforces that even more people to also prefer it during a subsequent time period, which again causes even more people to prefer it later and so on.

In his economic approach to attempting to predict, which technology might win in a market, Arthur points to the following four aspects as reasons for or fundamental components of self-reinforcing processes (cf. Arthur, 1994, p. 112):

- Large set-up or fixed costs give the advantage of falling unit costs to increased output.
- Learning effects act to improve products or lower theirs cost as their prevalence increases.
- Coordination effects confer advantages to "going along" with other economic agents taking similar action.
- And expectations act self-reinforcing where increased prevalence on the market enhances beliefs of further prevalence.

Thus, also the different reasons for path dependency that David described using the example of QWERTY can be considered as mechanisms causing and enhancing a self-reinforcing process. This can be used as a main argument for the existence of path dependency[22].

7.2.2 Institutions

In addition to the concepts of self-reinforcing processes and the role they play in path dependency, the subsequent proof of the statement that 'each institutionalization elementary is a self-reinforcing process' requires a definition of the understanding of an institution and thus what concept of an institutionalization it is based on.

individuals that contribute to the reinforcement, an attribute of a single actor that gets intensified, or the 'number of' fields of application, which grows when a pattern is increasingly transferred to related fields.

[22] Some authors also consider self-maintaining processes as leading to path dependency (e.g. Knapp, 2007). Therefore, it cannot be directly concluded that wherever path dependency exists, there must also be a self-reinforcing process because it could also be a self-maintaining process that keeps path dependency at a certain level. However, the only relevant direction of causality that remains necessary to draw conclusions – once the proof presented later in this chapter is completed – is that a self-reinforcing process, especially with a potential for a lock-in, leads to path dependency and increases it.

7.2.2.1 Notations of Institutions when Debated in Combination with the Concept of Path Dependency

There are different authors who combine institutionalism and the concept of path dependency in different fields of science.

7.2.2.1.1 Institutions as rules of the game

In the context of economics, North uses the (neoclassical economic) notation of an institution as 'rules of the game' (or 'solution to a problem') and distinguishes it from individuals or organizations who are the players of the game (North, 1990, 2006). He combines institutions with the concept of path dependency when he describes how institutions may be changed and that they can only be changed incrementally if actors with the same interests build organizations to reach their goal of altering an institution, i.e. agents get organized in interest groups to promote their interest in changing the rules of the game they play.

7.2.2.1.2 Political institutions in Political Science

In political science, Pierson states that 'every institution is path dependent' and uses this link to transfer the concept of path dependency to the usual institutional theory in political science (Pierson, 2000). But Alexander (2001, p. 253) argues that "formal political institutions are not, as a general category, path dependent". In order not to stretch the concept of path dependency too far, he uses the notation of path dependency for "patterns of cost and benefits such that rational actors prefer to maintain the status quo even if an alternative might provide higher aggregate returns in the long run" (Alexander, 2001, p. 254). In that context, he uses an economic interpretation of a possibly path dependent situation referring to 'rational actors' who make decisions based on their preference structure weighting transition costs. Furthermore, he argues that this (economic) concept cannot be applied to every formal political institution because it can be shown that political actors do not always decide entirely rationally according to economic definitions.

7.2.2.1.3 Discussion: the Process of the Institutionalization has been left out

What these arguments have in common in addition to using an economic understanding of path dependency, is that they all concentrate on the 'institution', trying to figure out whether it is path dependent or not[23]. They attempt to determine whether an institution can be described as a 'lock in' and therefore in terms of path dependency. The process that leads to the supposed lock-in is disregarded. In this chapter, a more process-oriented view is taken: Each institution is the result of a process of institutionalization[24].

7.2.2.2 The Process of Institutionalization

It is more relevant for the proof presented in this chapter, to address the combination of path dependency and 'institutionalization' instead of path dependency and institutions. In the context of organizational studies, Tolbert and Zucker (1996) present a description of the process of institutionalization. Their approach is neatly based on Berger and Luckmann's constructivist theory. But in contrast to Giddens' theory, which is also based on Berger and Luckmann's approach, Zucker assumes highly institutionalized social structures to be objective and exterior to actors instead of the internal and external perspective Giddens uses (Giddens, 1984; Zucker, 1977).

> "A much more adequate explanation can be found in the ethnomethodological approach to institutionalization, defining acts which are both objective (potentially repeatable by other actors without changing the meaning) and exterior (intersubjectively defined so that they can be viewed as part of external reality) as highly institutionalized" (Zucker, 1977, p. 726).

[23] Institutions are changing only incrementally due to path dependency. However, this is defined here in a more or less economic interpretation of actors choosing rationally and thus costs and benefits to be the main argument for their choice.

[24] It can be debated whether or not it is useful to address present institutions in a process manner of considering their former creation, which might have ended long ago and has perhaps not been well-documented. But path dependency is referred to as a concept for which 'history matters'. Therefore, it may be exactly this historical perspective that helps to gain a better understanding of the present situation of the considered institution.

7.2.2.3 Theoretical Positioning of the Notation of Institutionalization used in the subsequent proof

Since Zucker's process-oriented approach contradicts Giddens' theory but the latter is necessary for the subsequent proof, in which Giddens' theorem of the duality of structure is be used, the origins of both approaches need to be included in an underlying theoretical framework and a process oriented-approach needs to be created based on this framework that allows the application of Giddens' theorem.

Therefore, to create a basis for the proof that requires an approach to institutionalization as well as Giddens' theory of the duality of structure, first the essentials from Berger and Luckmann's theory are presented. Abstracting from the field of science, to which the concept of path dependency or institutionalization is applied, it can be stated that for each institutionalization there exists at least one actor who initiates this process of institutionalization and maintains it. If there was no actor who supports the institutionalization process (deliberately, mindfully or unconsciously), it would stop or would not start at all.

The consideration of the relationship of this creator to the institution which begins to exist in the description of the process of institutionalization is therefore an 'elementary' view of institutionalization because it can be applied to every single actor who supports a process of institutionalization.

7.3 Socialization and the Duality of Structure

7.3.1 Habitualization, Primary and Secondary Socialization

Elements of Peter Berger's and Thomas Luckmann's theory presented in 'The Social Construction of Reality – A Treatise in the Sociology of Knowledge' (Berger & Luckmann, 1979) are used in the development of the theoretical basis for the subsequent proof. Because of their description of primary and secondary socialization in an applied way referring to society in its entirety and to questions of knowledge, an adaptation is necessary to be able to apply it to institutions and the process of institutionalization.

7.3.1.1 Habitualization

To gain a better understanding of Berger and Luckmann's theory and to ensure that it matches with the different theories used in the subsequent proof, first the central aspects of habitualization are described and presented as the theoretical basis.

7.3.1.1.1 Institutionalization

Berger and Luckmann (1979) introduce institutionalization in the beginning of the book as one difference between humans and animals.

> "… All non-human animals, as species and as individuals, live in closed worlds whose structures are predetermined by the biological equipment of the several animal species. By contrast, man's relationship ... to the surrounding environment is everywhere very imperfectly structured by his own biological constitution" (Berger & Luckmann, 1979, p. 65).

These less biological predetermined structures allowed human beings to succeed in establishing themselves on all continents, different climate zones and the numerous surrounding environments. The peculiarity of man's biological constitution not only allows adaptability to natural environmental aspects but also provides opportunity for a great variety of activities: "This means that the human organism is capable of applying its constitutionally given equipment to a very wide and, in addition, constantly variable and varying range of activities" (Berger & Luckmann, 1979, p. 65).

These activities can be related to environmental aspects or to other human beings and can differ from human to human because they are not predetermined in detail by human biology. Humanness is socio-culturally variable. In other words, there is no human nature in the sense of a biologically fixed substratum determining the variability of socio-cultural formations.

> "… While it is possible to say that man has a nature, it is more significant to say that man constructs his own nature, or more simply, that man produces himself" (Berger & Luckmann, 1979, p. 67).

Consequently, human nature allows human beings to construct their own environment not only materially but also with regard to socio-cultural aspects. But although the human organism has the opportunity to construct its own surroundings to his needs, the basis to do so is determined by the process of "developing biological[ly] while already standing in a relationship to its environment" (Berger & Luckmann, 1979, p. 66). So the process of constructing an individual nature takes place for each human within the context of existing structures.

7.3.1.1.2 But how can the Process of Constructing his individual Nature be described and what do Social Structures consist of?

From the assessment of biological and developmental aspects of human organisms, Berger and Luckmann (1979) derive that habitualization is a centerpiece in the process of humans constructing their own nature: All human activity is subject to habitualization. Any action that is repeated frequently becomes a pattern, which can then be reproduced to reduce future efforts and which, ipso facto, is apprehended by its performer as that pattern. Habitualization further implies that the action in question may be performed repeatedly in the same manner and with the same economic efficiency. This is true for both non-social and of social activities.

> "… These processes of habitualization precede any institutionalization …" (Berger & Luckmann, 1979, p. 70).

So institutions are the result of processes of institutionalization, which are preceded by processes of habitualization. Berger and Luckmann state that empirically, the more important

part of the habitualization of human activity is coextensive with the latter's institutionalization (Berger & Luckmann, 1979, p. 71)[25].

7.3.1.2 Primary Socialization

Later in this chapter, the theory is applied to the elementary process of institutionalization to prove its self-reinforcing characteristics. If you assume that social structures consist of or are institutions, it is interesting to figure out how human beings relate the construction of their own nature to new or existing social structures and therefore to new or existing institutions. It is interesting to describe the process through which human beings construct their own nature in more detail. This process, when a human being first gets in touch with new institutions or social structures, is referred to as primary socialization by Berger and Luckmann. When humans are already are socialized to some extent, further processes are referred to as secondary socialization.

7.3.1.2.1 Society as Objective and Subjective Reality

Berger and Luckmann's assumption is that society exists both as objective and subjective reality (Berger & Luckmann, 1979, p. 149). When a child is born, the objective reality already exists but the child's subjective reality does not yet. This is the basis for primary socialization.

> "The beginning point of this process is internalization: the immediate apprehension or interpretation of an objective event as expressing meaning, that is, as a manifestation of another's subjective processes which thereby becomes subjectively meaningful to myself" (Berger & Luckmann, 1979, p. 149).

When a child is confronted with the objective reality without owning a subjective reality yet, it starts generating one: It tries to catch the meaning of an objective event.

[25] In their later detailed description of the process of externalization, 'institutionalization' is a process of "reciprocal typification of habitualized actions by types of actors" (Berger & Luckmann, 1979, p. 71).

7.3.1.2.2 Internalization

The process of creating an individual subjective understanding like an internal picture of the objective event is called internalization. This understanding then is associated with other internalizations and thus a subjective reality develops inside the child.

> "This does not mean that I understand the other adequately. I may indeed misunderstand him: he is laughing in a fit of hysteria, but I understand his laughter as expressing mirth. But his subjectivity is nevertheless objectively available to me and becomes meaningful to me, whether or not there is congruence between his and my subjective process. Full congruence between the two subjective meanings, and reciprocal knowledge of the congruence, presupposes signification, as previously discussed. However, internalization in the general sense used here underlies both signification and its own more complex forms. More precisely, internalization in this general sense is the basis, first, for an understanding of one's fellowmen and, second, for the apprehension of the world as a meaningful and social reality (Berger & Luckmann, 1979, p. 149)"

7.3.1.2.3 Social Reality: through Significant Others to the Generalized Other

Subjective realities can differ from human being to human being[26]. And although two people may share some aspects of objective reality in the same situation, they are likely to internalize it and thus interpret it differently. To gain an understanding of objective significance and the view of the 'world as a meaningful and social reality', it is necessary for a child to have 'significant others' who act in the same manner in comparable situations so that the child can understand the significance of it. Berger and Luckmann state that in the child's consciousness primary socialization creates a progressive abstraction from the roles and attitudes of specific others to roles and attitudes in general (Berger & Luckmann, 1979, p. 152).

[26] One human being's subjective reality can be different from someone else's.

> "This abstraction from the roles and attitudes of concrete significant others is called the generalized other. Its formation within consciousness means that the individual now identifies not only with concrete others but with a generality of others, that is, with a society. Only by virtue of this generalized identification does his own self-identification attain stability and continuity. He now has not only an identity vis-à-vis this or that significant other, but an identity in general, which is subjectively apprehended as remaining the same no matter what others, significant or not, are encountered (Berger & Luckmann, 1979, p. 153).

Primary socialization ends when this concept of the generalized other "has been established in the consciousness of the individual". Now the child "is an effective member of society and in a subjective possession of a self and a world" (Berger & Luckmann, 1979, p. 155).

7.3.1.3 Secondary Socialization in Comparison to Primary Socialization

While in primary socialization the individual's first world view is constructed (Berger & Luckmann, 1979, p. 155), later socialization is called secondary socialization. "Secondary socialization is the internalization of institutional or institution-based 'sub-worlds'. Its extent and character are therefore determined by the complexity of the division of labor and the concomitant social distribution of knowledge." (Berger & Luckmann, 1979, p. 158)

Berger and Luckmann then use the differentiation between primary and secondary socialization to address the aspect of knowledge, its social distribution, its evolution, and implications from it for society. For the subsequent proof in this chapter the question needs to be answered whether the process of institutionalization in the considered context contains more aspects of primary or more of secondary socialization. While it may be obvious that at least not every social institutionalization is made by babies – therefore not every institutionalization can be primary socialization and consequently secondary socialization needs to be applied – the process of institutionalization as defined in this chapter contains aspects of both primary and secondary socialization.

So for the transfer of the concept of primary and secondary socialization to the context of the subsequent proof it is interesting to determine, in which aspects they differ besides being first or second socialization and what similarities can also be observed.

7.3.1.3.1 Differentiation Criterion: choice of Significant Others

Significant others are necessary to understand the meaning and connection of actions, to create a subjective reality and understand the concept of a generalized other. "In primary socialization there is … no choice of significant others. Society presents the candidate for socialization with a predefined set of significant others, whom he must accept as such with no possibility of opting for another arrangement." (Berger & Luckmann, 1979, p. 154)

Opposed to this, in secondary socialization a world is already created and for the creation and understanding of new sub-worlds it is not necessary to always rely on the same 'significant others'. Instead, significant people and environments can change or be chosen intentionally and thus have a profound impact on the child or adult.

7.3.1.3.2 Differentiation Criterion: Intensity of Identification

In primary socialization, the intensity of identification is very high because it is the first world that is constructed and in this phase it is THE only one to the child and not merely one world out of many.

> "Since the child has no choice in the selection of his significant others, his identification with them is quasi-automatic. For the same reason, his internalization of their particular reality is quasi-inevitable. The child does not internalize the world of his significant others as one of many possible worlds. He internalizes it as the world, the only existent and only conceivable world, the world tout court. It is for this reason that the world internalized in primary socialization is so much more firmly entrenched in consciousness than worlds internalized in secondary socializations" (Berger & Luckmann, 1979, p. 154).

The emotional connection to his very first significant others is therefore very intense. In secondary socialization, with the optional differentiation between sub-worlds, the intensity of internalization and the identification with significant others in this particular surrounding can vary.

> "While primary socialization cannot take place without an emotionally charged identification of the child with his significant others, most secondary socialization can dispense with this kind of identification and proceed effectively with only the amount of mutual identification that enters into any communication between human beings. Put crudely, it is necessary to love one's mother, but not one's teacher. Socialization in later life typically begins to take on an affectivity reminiscent of childhood when it seeks radically to transform the subjective reality of the individual" (Berger & Luckmann, 1979, p. 161).

7.3.1.3.3 Similarity: Primary-like Socialization

However, secondary socialization can also occur with increasing or very high identification with significant others in a given surrounding. So although the first world already exists and a second one is created, the second one can serve as substitute for parts of the first world and the second world can become the new reality. The intensity of identification with significant others in the process of secondary socialization depends on its institutional necessity. The level of intensity it can increase up to (nearly) the level of primary socialization: Then this sort of secondary socialization can be called primary-like socialization.

> "When the process requires an actual transformation of the individual's 'home' reality, it comes to replicate as closely as possible the character of primary socialization, as we shall see a little later. But even short of such transformation, secondary socialization becomes affectively charged to the degree to which immersion in and commitment to the new reality are institutionally defined as necessary. The relationship of the individual to the

> socializing personnel becomes correspondingly charged with 'significance', that is, the socializing personnel take on the character of significant others vis-à-vis the individual being socialized. The individual then commits himself in a comprehensive way to the new reality. He 'gives himself' to music, to the revolution, to the faith, not just partially but with what is subjectively the whole of his life. The readiness to sacrifice oneself is, of course, the final consequence of this type of socialization" (Berger & Luckmann, 1979, p. 164).

7.3.2 Giddens' Structuralism and the Duality of Structure

While Berger and Luckmann's theory is based on the concept of 'habitualization', Giddens theory is based on Berger and Luckmann's theory but he uses the term 'routinization'. Giddens' theory of the duality of structure and Berger and Luckmann's theory of socialization are used in conjunction in the subsequent proof. In this section, Giddens' theory is introduced to allow a comparison to Berger and Luckmann's theory that is based on habitualization.

7.3.2.1 Giddens' Structuralism

7.3.2.1.1 Routinization

Giddens (1984) suggests "a fundamental concept of structuration theory – that of routinization":

> "The routine (whatever is done habitually) is a basic element of day-to-day social activity. I use the phrase 'day-to-day social activity' in a very literal sense, not in the more complex, and I think more ambiguous, way which has become familiar through phenomenology. The term 'day-to-day' encapsulates exactly the routinized character which social life has as it stretches across time-space" (Giddens, 1984, p. xxiii).

Although in his book, Giddens further concentrates on 'social life as it stretches across time-space' and how knowledge and structure relate and evolve in society, his basic theoretic assumptions fit the theories above and are based on the concepts of structure, the duality of structure, and, of course, the notation of routinization. The way he describes routinization is already reminiscent of action in the presence of path dependency as well as of key aspects of institutionalization.

> "Routinization is vital to the psychological mechanisms whereby a sense of trust or ontological security is sustained in the daily activities of social life. Carried primarily in practical consciousness, routine drives a wedge between the potentially explosive content of the unconscious and the reflexive monitoring of action which agents display" (Giddens, 1984, p. xxiii).

7.3.2.1.2 Social structure

Opposing structuration theory to functional approaches, Giddens states that 'structure' is usually understood by functionalists as some kind of 'patterning' of social relations or social phenomena (Giddens, 1984, p. 16).

> "Such conceptions are closely connected to the dualism of subject and social object: 'structure' here appears as 'external' to human action, as a source of constraint on the free initiative of the independently constituted subject. As conceptualized in structuralist and post-structuralist thought, on the other hand, the notion of structure is more interesting. Here it is characteristically thought of not as a patterning of presences but as an intersection of presence and absence; underlying codes have to be inferred from surface manifestations" (Giddens, 1984, p. 16).

So Giddens prefers the understanding of structure not only as a present appearance or 'external to human action', but more as an intersection of the present and the past: manifested

former actions intersected with present situational aspects. As such, ‘structure’ is closely linked to human agency:

> “To say that structure is a ‘virtual order’ of transformative relations means that social systems, as reproduced social practices, do not have ‘structures’ but rather exhibit ‘structural properties’ and that structure exists, as time-space presence, only in its instantiations in such practices and as memory traces orienting the conduct of knowledgeable human agents” (Giddens, 1984, p. 17).

7.3.2.1.3 Institutions

Thus ‘structure’ cannot exist apart from human agents as it consists of agents’ memories and agents’ practices. And Giddens defines institutions as special parts of structure: “The most deeply embedded structural properties, implicated in the reproduction of societal totalities, I call structural principles. Those practices which have the greatest time-space extension within such totalities can be referred to as institutions.” (Giddens, 1984, p. 17)

The criterion of having ‘the greatest time-space extension’ resembles the concept of institutions as an ultimate state or lock-in: ‘the greatest’ means that previous versions with a lower time-space extension are possible. At this point, Giddens leaves the process of institutionalization undefined and instead concentrates on the institution as a border or maximum version.

7.3.2.2 The Duality of Structure

Giddens’ main aspect of structure, which he uses throughout the book and his theory, is the ‘duality of structure’. It has already been touched when the notation of ‘structure’ was introduced, referring to that it is both internal and external, like an intersection of presence and absence. ‘The duality of structure’, being as well medium as outcome of human action, is summarized as follows:

> "The constitution of agents and structures are not two independently given sets of phenomena, a dualism, but represent a duality. According to the notion of the duality of structure, the structural properties of social systems are both medium and outcome of the practices they recursively organize. Structure is not 'external' to individuals: as memory traces, and as instantiated in social practices, it is in a certain sense more 'internal' than exterior to their activities" (Giddens, 1984, p. 25).

Later Giddens adds what in general describes the implications of the proof in the next section:

> "The duality of structure is always the main grounding of continuities in social reproduction across time-space. […] The flow of action continually produces consequences which are unintended by actors, and these unintended consequences also may form unacknowledged conditions of action in a feedback fashion" (Giddens, 1984, p. 26).

7.4 Proving the Statement: Each Institutionalization Elementary is a Self-Reinforcing Process[27]

As mentioned at the beginning of this chapter, an elementary perspective is used. In this context, it is assumed for the process of institutionalization that at least one actor exists who supports the process of institutionalization. This means that this actor in his subjective reality already holds an idea of at least a previous version of the later institution.

[27] This includes the potential for 'locking-in' an institution because institutions only change incrementally (North, 1990, 2006).

7.4.1 Description of the Process of Institutionalization

7.4.1.1 The Institution as Means and End of Action

Through institutionalization actors gradually build up social structures. When structures are first created, e.g. by repeated action, these created and therefore existing structures influence back on the actor, although initially perhaps with a very low intensity. This occurs because of the duality of structure (Giddens, 1984): As to the duality of structure, structure is means and end of action.

Thus structure is the result of the institutionalization but simultaneously also functions as a medium. Applying this description of an institutionalization, the beginning existence of an institution is a result of the actor's behavior. But as a medium it also affects the actor's next decisions and actions and in turn again influences the subsequent process of institutionalization.

7.4.1.2 The Institution Influences the Actor in a Process of Socialization

If one takes a closer look at this 'process of institutionalization', the institution that begins to exist re-influences the actor in a process of socialization (Berger & Luckmann, 1979). Now the question arises whether this is a process of primary or secondary socialization. Presumably, the actor is not a baby and thus the constructed institution is not one of the actor's 'first world'. So the concept of secondary socialization needs to be applied.

However, there is something special about this kind of secondary socialization: Because the actor is the one who created the surrounding, this process bears a resemblance to primary socialization. The institution, which starts to exist, perfectly fits the actor's subjective reality. Thus, this new social structure gives feedback of congruence to the actor. The longer this institution exists and the stronger it gets, the more the actor's significant others, which have been relevant for this institution, re-influence the actor in congruence with the actor's inner self. This means that by following the process of institutionalization, the creating actor is increasingly affirmed in his action of creating the institution.

Furthermore, the intensity of socialization, in which the new institution affects the considered actor, increasingly corresponds to the intensity of primary socialization because the significant others increasingly match the actor's subjective reality[28].

7.4.2 Concluding Proof

From the detailed consideration of socialization processes within the process of institutionalization it can be concluded that the actor's decisions are increasingly aligned with the process of institutionalization and 'with the institution'. Therefore, the institution's function as a medium strengthens the process of institutionalization, which then again results in a more intense institution, once again serving as result and medium and so on. This way, a feedback loop is integrated within the process of institutionalization, which has the effect that the resulting institution starts to get self-reinforced the very minute it begins to exist.

So every institutionalization elementary is a self-reinforcing process and thus the elementary increases path dependency[29].

7.4.3 Corollary

The above proof shows that if there is at least one actor who already carries an idea or image of the institution that is to be founded in his subjective reality, the process of institutionalization affects the agent in a self-reinforcing way. In each time step the newly founded and now growing institution feeds back on the one actor, and this institution also affects every other actor who resembles the initiator in a similar way: Thus the expanding institution affects each and every actor who already carries an idea or a preliminary version of

[28] Berger and Luckmann (1979) describe this phenomenon of different intensity with which institution creating actors are affected in contrast to distant actors who later have to be socialized in the context of first generation and second generation questions of adapting institutions.

[29] The elementary also shows the same attributes of path dependent processes. Because of the primary-like socialization, the actor's interpretation of the process' intensity can be far lower than the monitored intensity of an external observer. This may cause decisions and actions to follow the path longer than perhaps an objective analysis or a decision based on optimization criteria would recommend. So even the 'potential inefficiency', which is a typical attribute of path dependent processes, can occur and the decision or action 'using an institution' can describe the situation of a lock-in.

this institution in his subjective reality. This way the growing institution affects each of those actors inducing a self-reinforcing process and increasing their path dependency as well.

7.5 Linking Institutionalism and Path Dependency Theory

7.5.1 Institutions as Manifested Path Dependency

If you assume a path dependency theory that includes objects, which refer to the narrower and the broader aspects of path dependency, the following characteristics can be deduced: As shown above, every institution can be viewed as a path-dependent element because every institutionalization elementary is a self-reinforcing process with the potential to lock-in as an institution[30]. Therefore, a comparison of institutionalism as a theory, which is based on institutions as main objects, with path dependency theory, which is based on processes that are described as path-dependent, indicates that both theories have a lot in common:

Since every institutionalization elementary can be regarded as a path dependent process, the theory of institutionalization also must be part of path dependency theory. Because of the close ties between both theories, also the institution, which is the result of an institutionalization process, must be part of path dependency theory.

Consequently, if you reduced path dependency theory to the aspect of lock-ins, the object of path dependency theory would become equivalent to the objects of institutionalism: institutions. With this link between the two theories research about lock-ins using a narrow definition of path dependency is already included in institutionalism. With this conclusion in mind the question can be asked, how path dependency and its associated theory can be best defined to serve research interests that perhaps cannot entirely be answered merely with institutionalism yet?

[30] Institutions only change incrementally as North (1990, 2006) has described.

Path dependency theory has the option to use a slightly different perspective than institutionalism. It would simply include institutionalism when used on the same objects but would also offer the chance to be applied in a broader sense.

7.5.2 Path Dependency on the Micro Level: Actors' Role

The main focus of institutionalism is on institutions as a fundamental structure in society, which exists externally of actors (cf. e.g. Zucker, 1977). Actors cannot be totally ignored because they are the ones that rebuild institutions or may change them incrementally. However, these actors can be replaced and this way, institutions may survive generations of actors and still remain almost unchanged over time.

7.5.2.1 Application of Perspective of Path Dependency Theory (Definition on the Micro Level)

Path dependency literally means that an actor's decisions depend on a path. Such path dependency theory can be used to describe a more actor centered approach than institutionalism, which literally means 'theory of institutions'. For this kind of path dependency research a broader definition is suggested: 'Path dependency' should be considered as a variable that denotes how strongly an actor tends to decide path dependently[31].

7.5.2.2 A Broad Understanding, a General Approach

An actor acts path-dependently: This occurs when the actor's action depends on his (previous[32]) path, which he follows. Thus the subsequent decision depends on the path

[31] A variable of how strongly an actor tends to 'stick to a path'.

[32] It may be assumed that he rather needs to follow the 'present' path than the 'previous' one. But if you assume that there is an observer right at the moment of the actor's decision, the observer can only see that the actor acts path-dependently if there is a path he previously followed. This definition coincides with Arthur's and David's characterization of path dependency, in which they point out the fact of contingency at the beginning of paths. If the actor's decision at the origin of a new path is not influenced by previous paths, an observer cannot see that the actor decides 'path-dependently'. That particular decision then might appear to be more contingent than predictable.

followed before. Because of this effect, history matters. Decisions are not only related to present criteria but instead the perspective is chosen to consider previous actions as relevant for future decisions as well. Whether the actor follows a path deliberately and relates his own decisions intentionally to previous actions or not does not matter as from the perspective of path dependency an external observer can only see a decision process or action series that forms a trace of the actor's decisions and actions. And the observer can interpret any observed following behavior as being based on former decisions and would thus declare the actor to be acting path-dependently[33].

In this broad sense 'path dependency' seems to be observable in every decision except for totally random ones because in every decision or action at least one criterion may be the present situation, i.e. the situation before the 'next step' of action, for which the decisions are made that very moment. So for an observer any action in a given situation depends on the actions and the previous situation, therefore history matters[34]. Consequently, in this broad sense, every action can be considered to be path dependent[35].

7.5.2.3 Increasing Path Dependency

It is interesting to regard path dependency no longer simply a binary criterion that can be either 0 or 1 or a process as being either path-dependent or not path-dependent. Since every action and thus every process is path-dependent it is even more interesting to consider the degree of path dependency and thus look at it as a dynamic variable that can increase or decrease.

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[33] It can be described as: 'past dependence' + 'a path can be assumed, on which the actor depends' = 'path dependence'.

[34] Considering perfectly random actions, which appear to be rare, because they require substantial luck as they are based on successful interaction without destroying or hurting the own or other actors' surroundings. It may be asked why it should be possible to perfectly randomly choose an action and if it is deliberately chosen, this mere 'reason' again may relate the performed action to expectations, which are based on experiences or a mindful design of the situation to allow random choices, and therefore on 'history'. So an actor who acts totally randomly can be regarded as a very unstable appearance if such kind of actor is possible at all.

[35] Other authors judged such a 'general' understanding as being 'too general' to be useful at all (e.g. Page, 2006; Sydow et al., 2005, 2009). Thus they would conclude a uselessness of the whole theory, which is based on the generality of the basic definition and thus from the generality of the theory's applicability. However, there are other theories that are particularly successful because of their very generality, like e.g. the nuclear or molecular theory.

For example, in a self-reinforcing process path dependency is increased: Self-reinforcing means there is a 'self' who reinforces the process and thus reinforces the actor to maintain the process. And each time the 'self' gets reinforced, the 'self' increases and again the reinforcement increases and thus the intensity for the actor to decide accordingly to the process increases. So this way a self-reinforcing process increases the actor's path dependency[36].

7.5.3 Path Dependency on Macro Level: Institutions as Manifested Path Dependency

Each institution can be interpreted as the result of an institutionalization process of this institution. For example, a standard is the result of standardization, and a habitude is the result of habituation etc.[37] So each institution is the result of a self-reinforcing process, which increased path dependency and also as a medium continues to affect actors to decide and act path dependently through its mere existence as part of social structure and its duality (Giddens, 1984).

Using this interpretation, it is not only possible to define path dependency on the micro level as a variable of how intensely an actor sticks to a path in his decisions and actions. It can further be used in a macro-perspective to define path dependency as an aggregated variable of how intensely members of a particular group, people in a defined area, actors discussing a given subject, or also global society, tend to decide and act path-dependently on e.g. group-, area-, subject-, or societal issues. From the macro-perspective it can be concluded that the higher the degree of institutionalization with regard to in the considered aspect is, the higher the path dependency of the involved actors turns out to be.

7.5.4 Multi-Level Conclusions on Societal Path Dependency

To get an impression of an actor's path dependency, which is the intensity to stick to a path with his decisions and actions and thus a micro-variable, the macro-perspective of institutions

[36] This is explained in detail to show that the dynamic approach is consistent with the other definitions of path dependency that were stated at the beginning of this chapter.

[37] The neoclassical definition of an institution can be considered for these two examples (Meyer & Rowan, 1977).

can be used: The higher the level of institutionalization and thus the stronger the influence of institutions on the involved actors, the higher is the path dependency of each involved actor.

However, like every aggregated data this deduction from the aggregated macro level to the micro level more describes the trend or the average and it can still differ from actor to actor as grades of socialization and influences of institutions differ from individual to individual. But this perspective can still be useful, as e.g. rising standardization, or an increase in the level of regulation and thus the founding of more institutions and an associated rise of the level of institutionalization can be predicted as an increase in path dependency.

In contrast to primary-like socialization of the involved actors in an institutionalization process, the later effects of an existing institution as a social structure and a medium on another actor need not result in the affected actor's commitment. Instead, they can also cause an opposite reaction of the actor. Nonetheless, the intensity, with which the actor is affected, is an indicator of the intensity of his or her path dependency. Path dependency in the described sense does not precisely imply the 'direction' of the actor's commitments but simply represents an average intensity of how the considered actor sticks to his or her individual paths.

7.6 Conclusion

The theory presented in this chapter describes social science theories in a mathematical way to prove that every institutionalization elementary is a self-reinforcing process. While in an empirical approach it would have been necessary to first generate a typology of every possible institutionalization and then at least show in practice for each single type that the hypothesis is true, on the presented level of abstraction it is possible to complete the proof without any further characterization or the necessity to show separately that really all possible types were actually considered.

The assumptions for the proof were in line with Berger and Luckmann's (1979) theory of socialization and Giddens' (1984) theory of the duality of structure. And in the elementary

approach it is assumed that in each process of institutionalization, there is always at least one actor who supports that particular process[38].

Remaining on this level of abstraction, the theories of institutionalism and path dependency can be compared using the just proven hypothesis as a linkage between both. If there are two theories describing basically same elements, it may be asked what the two perspectives describing the same phenomena or objects can be used for. As an answer, a basic structure for a path dependency theory is presented that bridges the gap between the macro and the micro level for transferring hypotheses or facts from one level to the other, from society to the individual level, from institutionalism to action or decision theory. "Unfortunately, analysts have yet to define the concept 'path dependence' in a manner that demonstrates why path-dependent patterns and sequences merit special attention." (Mahoney, 2000, p. 507)

In this paper, a theoretical basis is provided for 'intertheoretical' work using the presented linkage between institutionalism and path dependency theory as well as for a multilevel approach using path dependency theory.

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[38] 'Supporting' in this context does not necessarily imply a positive connotation.

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Appendix

Table of contents

Appendix 1: Supplementary material for chapter 2

Supplementary Material

Jürgen Scheffran, Michael Brzoska, Jasmin Kominek, P. Michael Link & Janpeter Schilling (2012):

Climate Change and Violent Conflict, *Science*, **336**: 869-871.

database	provider	scale	resolution	key variables	source
conflict databases					
UCDP/PRIO Armed Conflict Dataset	Uppsala Conflict Data Program	global	country level, annual, 1946-2010	number of conflict-years; conflict year is one with at least 25 battle-related deaths.	http://www.pcr.uu.se/research/ucdp/datasets/ucdp_prio_armed_conflict_dataset/
UCDP Georeferenced Event Dataset	Uppsala Conflict Data Program	Africa	point resolution of the event, annual, 1989-2010	geo references, state-based, non-state and one-sided violence leading to at least one death	http://www.pcr.uu.se/research/ucdp/datasets/ucdp_ged/
UCDP Non-State Conflict Dataset	Uppsala Conflict Data Program	global	country level, annual, 1989-2010	conflicts of non-state-actors, three organizational levels distinguished, estimates of deaths	http://www.pcr.uu.se/research/ucdp/datasets/ucdp_non-state_conflict_dataset_/
UCDP One-sided Violence Dataset	Uppsala Conflict Data Program	global	country level, annual, 1989-2010	violence of a government or organized group against civilians with at least 25 deaths, estimates of deaths	http://www.pcr.uu.se/research/ucdp/datasets/ucdp_one-sided_violence_dataset/
UCDP Battle-Related Deaths Dataset	Uppsala Conflict Data Program	global	country level, annual, 1989-2010	number of deaths in armed conflicts that have totaled at least 25 casualties	http://www.pcr.uu.se/research/ucdp/datasets/ucdp_battle-related_deaths_dataset/

database	provider	scale	resolution	key variables	source
conflict databases (continued)					
Correlates of War Non-state War Dataset	Correlates of War Project	global	country level, one record per conflict, 1816-2007	parties involved in conflict, start and end of conflict, initiator, result, number of fatalities	http://www.correlatesofwar.org/
Correlates of War Intra-State War Dataset	Correlates of War Project	global	country level, one record per conflict party, 1816-2007	parties involved in conflict, start and end of conflict, initiator, result, number of fatalities	http://www.correlatesofwar.org/
Correlates of War Inter-State War Dataset	Correlates of War Project	global	country level, one record per conflict party, 1816-2007	parties involved in conflict, start and end of conflict, initiator, result, number of fatalities	http://www.correlatesofwar.org/
Correlates of War Extra-State War Dataset	Correlates of War Project	global	country level, one record per conflict party, 1816-2007	parties involved in conflict, start and end of conflict, initiator, result, number of fatalities	http://www.correlatesofwar.org/
KOSIMO Database/ Conflict Information System	Heidelberger Institut für Internationale Konfliktforschung	global	country level, one record per conflict, 1942-1998	parties involved in conflict, start and end of conflict, issues at stake, location, resolution, result of conflict, estimate of casualties	http://hiik.de/de/kosimo/index.html
Armed Conflict Location and Event Data (ACLED)	Centre for the Study of Civil War, International Peace Research Institute, Oslo	Africa, Balkan, other countries	point resolution of the event, annual, 1997-2010	geo references, parties involved in conflict, start and end of conflict, location, estimate of fatalities	http://www.acleddata.com/
Inventory of Conflict and Environment	American University of Washington	more than 200 indivi-dual case studies	varying spatial and temporal resolution, depending on case study	location, habitat affected, detailed description of conflict background, actors, environmental setting, type of conflict, fatalities, link between conflict and the environment	http://www1.american.edu/TED/ice/ice.htm

database	provider	scale	resolution	key variables	source
conflict databases (continued)					
International Crisis Behavior Project	Center for Int'l Development and Conflict Management, University of Maryland	global	country level, one record per conflict or conflict party, 1918-2007	crisis dimensions, duration of conflict, intensity, conflict parties involved, location, result, categorization of conflict, mediation of the crisis	http://www.cidcm.umd.edu/icb/
Event Data Project on Conflict and Security	Freie Universität Berlin	Sub-Saharan Africa	point resolution of the event, annual, 1990-2007	geo references, date, location, actors, fatalities, event type (one-sided violence, fighting, suicidal bombings, landmines, conventional weapon attacks)	http://www.sfb-governance.de/teilprojekte/projekte_phase_1/projektbereich_c/c4/The_EDACS/index.html
International Military Intervention Dataset	Kansas State University	Global	one record per conflict, daily, 1946-2005	parties involved in conflict, start and end of conflict, type of conflict, casualties	http://www.k-state.edu/polsci/intervention/
Small Arms Trade Database	Norwegian Initiative on Small Arms Transfers	global	searchable database, country to country, annual, 1962-2010	transfers of small arms between countries, number of weapons, estimated value, licenses	http://www.prio.no/NISAT/Small-Arms-Trade-Database/
Social Conflict in Africa Database	Robert S. Strauss Center for International Security and Law	Africa	country level, one record per conflict, daily, 1990-2010	parties involved in conflict, type and issue of conflict, location, start and end of conflict	http://ccaps.strausscenter.org/scad/conflicts
Behavioral correlates of war	R.J. Leng, Middlebury College	selected countries	country level, 40 selected crises between 1816 and 1979	parties involved in conflict, start and end of conflict, location, estimate of fatalities	http://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/8606
Conflict and Mediations Event Observations	The Kansas Event Data System	Balkan, Levant, West Africa	daily, 1979 or 1989-2002	detailed description of the mediation of conflicts	http://web.ku.edu/~keds/data.html

database	provider	scale	resolution	key variables	source
conflict databases (continued)					
Transboundary Freshwater Dispute Database	Oregon State University	six databases	watershed level, varying temporal extent	geo references (in part), emphasis on conflict resolution processes, international water relations, treaties. Spatially referenced biophysical, socioeconomic and geopolitical data	http://ocid.nacse.org/tfdd/

database	provider	scale	resolution	key variables	source
societal stability databases					
Social, Political and Economic Event Database	Cline Center for Democracy, University of Illinois	global	point resolution of the event, one record per incidence, daily, 1946-2011	geo references, type and intensity of the event, location and date, how and why of event, targets/victims, fatalities	http://www.clinecenter.illinois.edu/research/speed.html
Geographic Distribution of Climate Change Vulnerability	Socioeconomic Data and Applications Center, Columbia University	global	country level, two points in time, projections for 2050 and 2100	vulnerability of countries to climate change by means of an index based on human resources, economic capacity and environmental capacity, infrastructure, food security, ecosystems, human health and water resource	http://sedac.ciesin.columbia.edu/mva/ccv/index.html
Polity IV Political Regime Characteristics and Transitions Database	Center for Systemic Peace	global	country level, annual, 1800-2010	indices of democracy and autocracy, indicators for the characterization of state authority, transitions between different polity regimes	http://www.systemicpeace.org/polity/polity4.htm
Political Rights Index	Freedom House	global	country level, annual, 1972-2008	index of political freedom	http://www.freedomhouse.org/

database	provider	scale	resolution	key variables	source
societal stability databases (continued)					
Political Terror Scale	www.politicalterrorscale.org	global	country level, annual, 1976-2010	index of human security based on annual reports by amnesty international and the U.S. State Department	http://www.politicalterrorscale.org/
Failed State Index	The Fund for Peace	global	country level, annual, 2005-2011	index of state functioning that is based on a composite score from twelve social, economic and political and military indicators	http://www.fundforpeace.org/global/?q=fsi
Global Peace Index	Institute for Economics and Peace	global	country level, annual, 2007-2011	index of peacefulness in countries based on 23 qualitative and quantitative indicators	http://www.visionofhumanity.org/info-center/global-peace-index-2011/
Alliance Treaty Obligations and Provisions	Rice University	global	country level, daily, 1815-2003	treaties between countries, start and end dates, member countries, contents, effectiveness	http://atop.rice.edu/data
Minorities at Risk	Center for International Development and Conflict Management, University of Maryland	global	country level, one record per minority group, annual, 1980-2006	demographic characteristics of minority groups, conflicts, 71 indicators total	http://www.cidcm.umd.edu/mar/data.asp

database	provider	scale	resolution	key variables	source
disaster databases					
EM-DAT International Disaster Database	Centre for Research on the Epidemiology of Disasters	global	searchable database, country level, annual, 1900-2011	search by geographic location, time period and disaster category: number of disasters, fatalities, affected, economic damages	http://www.emdat.be/

database	provider	scale	resolution	key variables	source
risk indicator databases					
Global Climate Risk Index	Germanwatch	global	country level, annual, 1991-2010	index based on data of impacts of extreme weather events and corresponding socio-economic indicators	http://www.germanwatch.org/klima/cri.htm

database	provider	scale	resolution	key variables	source
data collections					
Paul Hensel's General International Data Page	University of North Texas			overview of databases on states and the international system, state capabilities, alliances, and various geographic and social science indicators	http://www.paulhensel.org/dataintl.html

Table 5 Characteristics of key databases on indicators of conflict, societal stability, and disasters.
UCDP-PRIO: Uppsala Conflict Data Program–Peace Research Institute Oslo.
Geo-referencing uses WGS84 (World Geodetic System Datum 84)

Appendix 2: List of own publications

Publications that are chapters in this dissertation

chapter 2: own contribution: 20%

Scheffran, J., Brzoska, M., Kominek, J., Link, P.M. & Schilling, J. (2012): *Climate change and violent conflict*, **Science**, 336, pp. 869-871.

chapter 3: own contribution: 20%

Scheffran, J., Brzoska, M., Kominek, J., Link, P.M. & Schilling, J. (2012): *Disentangling the Climate-conflict Nexus: Empirical and Theoretical Assessment of Vulnerabilities and Pathways*, **Review of European Studies**, 4 (5).

chapter 4: own contribution 100%

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Appendix 3: Curriculum Vitae

entfällt aus datenschutzrechtlichen Gründen