Heidelberg University
Faculty of Economics and Social Sciences
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Doctoral Thesis

International Institutions in an Uncertain Environment

Success and Failure of Regime Formation in the Context of Complex Policy Issues

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Declaration of Authorship

I, Wolfgang Dietz, declare that this thesis titled, 'International Institutions in an Uncertain Environment' and the work presented in it are my own. I confirm that:

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- Where I have consulted the published work of others, this is always clearly attributed.
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"Basically, I get paid to way overanalyse things – so great because I would be doing that anyway."

Anna-Maria Huber

HEIDELBERG UNIVERSITY

Abstract

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International Institutions in an Uncertain Environment

by Wolfgang Dietz

In a *global risk society* (Beck, 2009), two interlinked developments increase complexity on environmental policy issues: On the one hand, unilateral problem solving is often ineffective in a globalized world. On the other hand, many environmental issues themselves are becoming increasingly complex. States have addressed these challenges by forming international institutions and regimes to collectively deal with environmental problems. But why do states form international environmental regimes on some issues while they fail to do so on others? How do states deal with scientific uncertainty on complex environmental issues and to what extent can scientific uncertainty account for success or failure of regime formation process? This dissertation provides insights on regime formation on highly complex policy issues by theorizing on how scientific uncertainty frames actors' perception of an issue. It is argued that actors are tolerant towards uncertainty on some aspects of an issue while they are not on others. This argumentation is empirically tested against four cases of international regime formation, two successful ones and two failed regime formation processes. The dissertation finds evidence that actors are more tolerant towards scientific uncertainty if it only affects the assessment of benefits while costs are at the same time estimated to be low.

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My parents have always nurtured my interests in politics and were the main reason for the choice of my field of study. They supported my academic pursuit and I could always rely on them, and my parents in-law Franca and Reinhold Füger, when balancing research, work and kids became difficult from time to time.

My deepest gratitude, however, goes to my wife Simona for sticking with me through times of frustration, for her imperturbable belief in my abilities and for helping me to keep my sanity. Undoubtably, this dissertation could not have been written without her. Last but not least, my kids Samuele and Serena have to be mentioned for doing their best and their worst to keep me from writing this dissertation and for reminding me what *really* matters. With deep love, I dedicate this dissertation to them.

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Abbreviations

AMAP	**A**rctic **M**onitoring and **A**ssessment **P**rogramme
CBA	**C**ost **B**enefit **A**nalysis
CCD	**C**onvention to **C**ombat **D**esertification
CCOL	**C**oordinating **C**ommittee on the **O**zone **L**ayer
CFCs	**C**hlor **F**luoro **C**arbons
CO2	**C**arbon **Dio**xide
FAO	**F**ood and **A**gricultural **O**rganization of the United Nations
IEA	**I**nternational **E**nvironmental **A**greement
IGO	**I**nternational **G**ouvernemental **O**rganizaition
IMOS	**F**ederal **T**ask **F**orce on **I**nadvertent **M**odification of the **S**tratosphere
IPCC	**I**nternational **P**annel for **C**limate **C**hange
IPCS	**I**nternational **P**rogramme for **C**hemical **S**afety
IPF	**I**ntergovernmental **P**anel on **F**orests
IR	**I**nternational **R**elations
ITTA	**I**nternational **T**imber **T**rade **A**greement
ITFF	**I**nter-**A**gency **T**ask **F**orce on **F**orests
MSSD	**M**ost **S**imilar **S**ystems **D**esign
POPs	**P**ersistent **O**rganic **P**ollutants
UNEP	**U**nited **N**ations for **E**nvironmental **P**rogramme
UNECE	**U**nited **N**ations **E**conomic**C**ommission for **E**urope
UNFCCC	**U**nited **N**ations **F**ramework **C**onvention on **C**limate **C**hange
WHO	**W**orld **H**ealth **O**rganization
WMO	**W**orld **M**eteorological **O**rganization

For Simona & Samuele & Serena

Chapter 1

Introduction

"There are known knowns; there are things we know we know. We also know that there are known unknowns, this is to say we know that there are things we do not know. But there are also unknown unknowns: the ones we don't know we don't know."
– Donald Rumsfeld

"Il n'est pas certain que tout soit incertain."
– Blaise Pascal

In a *global risk society* (Beck, 2009), policy issues are becoming increasingly complex and political decision-making has to be made in the shadow of an uncertain future. In environmental policy, complexity is twofold: On the one hand, complexity is often caused by nature itself. On many issues, biological, physical and chemical mechanisms are highly interlinked, causing feedbacks, tipping points and chain reactions on different scales. While policy-makers depend on precise information to make sound decisions, natural science is often at the edge of knowledge on these issues with conflicting models and rivaling research results. On the other hand, many environmental issues involve a transboundary dimension where unilateral action is ineffective. Many issues can only be resolved through multilateral cooperation in the form of institutionalized international regimes. Reaching such a multilateral agreement among actors with divergent interests and different normative convictions is a complex process in itself. The combination of complex natural processes and interaction of social actors make these cases of regime formation on complex policy issues unique. However, social science has to a large extent focused on the latter and neglected the effect of uncertain scientific findings on political decision making. This study approaches the question why and how states form international environmental regimes on complex policy issues. Furthermore, this study sheds light on the question why states form international regimes on some uncertain issues whilst refusing to cooperate on others?

The focus of this dissertation on scientific uncertainty blends in with two research traditions: It stands in the tradition of institutionalism in international relations (Abbott and Snidal, 1998; Axelrod and Hamilton, 1984; Keohane and Nye, 1977) and its sub-discipline, the study of international regimes (Hasenclever et al., 1997; Krasner, 1983; Rittberger and Mayer, 1993). Scholars of international regimes can benefit from this dissertation, because it offers a refined theoretical framework that integrates different and previously separated theoretical traditions in regime theory. It furthermore enhances the body of empirical work on international regimes by adding case-studies on international regimes as well as empirical cases of failed attempts of regime formation that have not been studied in such detail before. Scholars that have an interest in the role of ideas in politics and international relations may find this dissertation worth reading, because this study picks up on the literature about cognitive biases in international relations (Goldgeier, 2001; Levy, 1992; McDermott, 2004) and the role of models and ideas (Blyth, 1997; Chwieroth, 2007; Goldstein and Keohane, 1993; Lieberman, 2002; Parsons, 2002) to integrate *science* as a provider of ideas that influence political decision making. Not only does this have implications for environmental politics, but for policy issues where scientific models and ideas shape the perspective of actors. To explain the behavior of social actors, it may be useful to turn to the *science-induced perception* of the world; a focus on scientific knowledge in international politics is informative in this regard.

The book investigates international political action on four environmental policy issue areas that are characterized by scientific uncertainty (Persistent Organic Pollutants, Stratospheric Ozone, Arctic haze, and global deforestation). The comparative perspective between two cases where regime formation was successfully completed (Persistent Organic Pollutants and Stratospheric Ozone) and two cases where regime formation failed (Arctic haze and global deforestation) allows to more rigorously identify factors that facilitate or hamper regime formation under scientific uncertainty than previous single-case studies had been able to do.

1.1 Research Gaps and Goals of this Book

The dissertation aims at closing three standing gaps in the study of international regimes. The first one is of theoretical nature. In this study, it is argued that regime theory either neglects scientific uncertainty or draws implausible conclusions from its existence. In order to overcome this shortcoming, this study offers an integrated theoretical framework, which regards scientific uncertainty as a factor that influences state interests towards institutionalized cooperation. It is argued that scientific uncertainty does not simply facilitate or hamper the formation of international regimes. Rather, this study pursues an argument that focuses on the specific aspect which is affected by scientific uncertainty. The second gap concerns research design and methodology. Regimes study has for the most part relied on single-n (or small-n) case studies about successfully installed international regimes. While this is ideographically informative, this methodological choice runs the danger to cause a bias towards positive findings. To a large extent, regime studies that intend to identify factors that are causally linked to regime formation are lacking a control group (Dimitrov et al., 2007). The third gap that this study intends to close is of empirical nature. The study offers detailed case studies not only of the political process that has led to success or failure of regime formation, but it also provides a detailed account on how scientific knowledge has evolved in parallel to the political process of regimes and non-regimes.

1.2 Major Arguments in Brief

Starting from a rationalist paradigm, this study presumes rational actors that try to maximize their utility according to their individual cost-benefit-calculations. Actors can be expected to form a regime, if benefits exceed costs. They can be expected to block an international regime formation process if costs exceed benefits. It is therefore a specific configuration of costs and benefits that leads to successful or unsuccessful regime formation. In order to assess individual costs and benefits, actors depend on information. More specifically, actors depend on a whole set of information to assess costs and on a whole set of information to assess benefits.

As argued earlier, information can be highly uncertain in the context of environmental politics. For actors, this implies that they may be able to determine their costs, but have trouble to determine their benefits, or vice versa. The main argument of this study is that in the light of scientific uncertainty there are still configurations that are conducive for successful regime formation. On the other hand, there are configurations which are obstructive for regime formation. More specifically, *if costs are expected to be low and benefits are uncertain, regime formation is more likely* and *if costs are uncertain and benefits are low, successful regime formation is more unlikely.*

1.3 Outline of the Book

Starting form a review of the theoretical and empirical literature on international regimes, as well as a review of concepts of uncertainty in chapter 2, the study develops a refined concept of uncertainty and identifies three major gaps in the study of international regimes. These gaps are picked up in chapter 3, which elaborates on a theoretical framework in order to close gaps at a theoretical level. This allows the formulation of a set of testable hypotheses. Chapter 4 is of technical nature and explores how the hypotheses are operationalized and empirically tested.

The chapter explains and justifies methodological choices. Chapter 5 contains the empirical analysis. To test the argument, this study has retraced the historical developments of the scientific and political process of four empirical cases. The results are presented and interpreted in chapter six, which also addresses alternative explanations, implications for research and politics and an outlook on the future research agenda.

Chapter 2

Cooperation and Uncertainty in Social Science Literature

This study is concerned with regime formation and uncertainty. Both issues have already been addressed by a vast body of literature. This chapter reviews theoretical accounts on international regimes in order to identify major theoretical paradigms in the field. The chapter also reviews empirical regime study to profit form idiographic insights as well as methodological approaches that have been employed in empirical regime study. Thirdly, the chapter reviews the literature on uncertainty with a special focus on international relations. The review reveals three major gaps in regime study. It shows how common concepts of uncertainty rest primarily on knowledge about probabilities and how this can be misleading. The review furthermore shows how uncertainty in international relations has been treated either as a strategic feature, or as the ambiguity of information about complex real-world issues. While the latter concept of *scientific* uncertainty better reflects the challenges of environmental issues, the review also shows that theoretical approaches that use such a concept often have their shortcomings. More precarious, the review of theories on international regimes shows how theoretically separating scientific uncertainty and strategic interaction forfeits explanatory value on many issues of international cooperation. Concerning methodology, the review of empirical regime study shows that the field tends to be bias towards positive findings, since empirical regime study to a large extend omits the whole range of variance of the dependent variable. In other words, regime study is mainly concerned with the successful creation of international regimes.

2.1 Regime Study – A Review of Theory and Empirical Applications

Starting from Krasner (1983)'s prominent, yet wholly and broad definition (Haggard, 1987) of an international regime as "implicit or explicit principles, norms, rules and decision-making procedures around which actors' expectations converge in a given area of international relations" (Krasner, 1983, :1), regime definitions can be categorized into formal, behavioral and cognitive definitions (Hasenclever et al., 1996). This study follows Young (1989)'s formal definition, where international regimes are regarded as "specialized arrangements that pertain to well-defined activities, resources, or geographical areas and often involve only some subset of the members of international society" (Young, 1989, :13). His definition has been narrowed down by Dimitrov (2006), who defines an international regime as "... a formal intergovernmental agreement that involves specific commitments to policy targets and timetables" (Dimitrov, 2006, :5). This definition admittedly omits a variety of non-explicit or uncodified international regulations and patterns of behavior, such as for example international customary law. However, the pragmatic definition allows more traceable observations of actors' behavior and is therefore more suitable for the empirical research of this study.

Scholars found increasing interest in rule-based international coordination in the 1970s (Haas, 1975; Ruggie, 1975) as a response to mainstream work on international relations (Breitmeier et al., 2006). As realist assumptions about international regimes as the epiphenomenal execution of hegemonial power proved more and more inadequate to explain the existence of international regimes despite the absence of a hegemon, scholars turned to the *interests* of rational states that seek to realize gains from cooperation. While the realist assumptions of rational, self-interested states as the main actors in an anarchic international structure are adopted from realism, states are not pictured as unitary actors that share the same desire for power (Grieco, 1988; Strange, 1982; Waltz, 2001); rather, they are pictured to posses individual preferences and interests of which some can only be realized through mutual cooperation. Even though cooperation can be expected to improve the outcome towards Pareto-efficency, anarchy in the international system of sovereign states leads to dilemma-situations in which non-cooperation is the dominant strategy for all players (Dawes, 1975; Hardin, 1968; Olson, 1965). International regimes can change the pay-off structure in such a way that cooperation becomes the dominant strategy by providing information, reducing transaction costs and punishing deviation (Keohane, 1982).

Therefore, international regimes enable states to realize common interests and to overcome different collective-action problems. According to supporters of interest-based explanations, regimes come into existence "... because they could have reasonably been expected to increase the welfare of their creators." (Keohane, 1984). By employing game theoretic micro-foundations, interest-based regime-theory impressively shows how self-interested states can maximize their gains through rule-based cooperation in an international self-help system (Finus, 2002; Kydd and Snidal, 1997). Rather than serving a dominant powers' interests, regimes provide specific functions that are demanded by states to realize gains from cooperation. Thus, an interest-based hypothesis about regime-formation can be summarized by the following: "An agreement is struck and a regime forms when the participants reach closure on the terms of a mutually acceptable constitutional contract." (Young, 1993, :11). The original approach was extended by Zürn, who notes that the classical prisoners' dilemma is not the only game that resembles settings in international relations. Within his situation-structure-framework, he claims that different game structures imply different dilemma situations which has an impact on the likelihood and types of regime formation (Zürn, 1992).

Despite sharing common grounds with political science, scholars from economics think differently about international regimes. Literature from economics on international environmental agreements (IEAs)[1] employs the same logic as an interest-based approach, but models cooperation in a more rigorous economic fashion. This strand of literature adds two major insights to our understanding of rule-based cooperation. First of all, Barrett (1994) shows that IEAs have to be self-enforcing, since no sovereign state can be forced into signing an agreement. He further argues that states have to be symmetrical in their structure of preferences to have an incentive for cooperation. The concept of symmetry reflects the political-science concept of mutual interests towards cooperation and will be reviewed later in this chapter. Secondly, in a later version of his model, Barrett (1994) shows how rule-based cooperation can be 'bought' through side-payments and issue-linkage (Barrett, 2001). Buying cooperation eventually levels asymmetry between states. Rationalistic game-theoretic approaches that emphasize the importance of national interests have enormously enhanced our understanding of international cooperation by pointing out why states do not cooperate *despite* mutual expected benefits and how international regimes can resolve this situation.

The strong assumptions that are implied in game-theoretic models of international environmental cooperation have been challenged by regime-scholars who are dedicated to a so-called 'knowledge-based approach' (Haas, 1980) or 'cognitivism' (Hasenclever et al., 1996). Especially the assumption of fully informed rational actors has been a target of criticism. Cognitivist criticism is, however, not articulated in the radical fashion of the theoretical tradition labeled as 'social-constructivism' in which the rationalistic 'logic of consequences' is confronted with a 'logic of appropriateness' (Wendt, 1992). Rather than questioning the assumption of rational self-interest driven actors, cognitivists argue that the assumption of adequate and complete information becomes more and more questionable in a world of increasingly complex policy issues. Cognitivists contend that ambiguity of information has an impact on the information-processing ability of rational actors.

[1] since IEA refers to the same empirical phenomena as regimes, the two terms will be used synonymously

With this in mind, decision-makers are pictured as being unable to adequately formulate interests and struggle to set up pay-off matrices. Cognitivists draw on the literature from psychology in international relations (Goldgeier, 2001; Jervis, 1976; McDermott, 2004; Young and Schafer, 1998) and integrate works on the role of ideas and models in foreign policy (Chwieroth, 2007; Goldstein and Keohane, 1993; Jachtenfuchs, 1995; Lieberman, 2002). These considerations lead cognitivist scholars to three assumptions: Firstly, the demand for international regimes depends on actors perception of international problems, which is, in part, produced by their causal and normative beliefs (Hasenclever et al., 1997, :137). This implies that (a) information does not speak for itself but must be interpreted and (b) interpretation depends on the body of knowledge that actors hold (Hasenclever et al., 1997, :206). Secondly, before actors can agree on the terms of collectively treating an international issue, they have to agree on a shared consensual definition of the nature and the consequences of the issue at stake (Dimitrov, 2006; Haas, 1992a). Thirdly, states want to reduce uncertainty by acquiring more knowledge where science and international epistemic communities are the main provider of new knowledge. If - as Keohane (1982) states - the chance of realizing common interests is a prerequisite for a regime-formation, cognitivist scholars find it reasonable to turn to the question of how these interests form in the first place (Haas, 1980).

Empirically, the study of international regimes predominantly rests on single-n or small-n comparative case studies. (Moravcsik, 2000; Nayar, 1995; Raustiala and Victor, 2004; Underdal, 2002; Young, 1993). As Hasenclever et al. (1996) conclude, the authors ask questions on "...what accounts for the emergence of rule-based cooperation in the international system? How do international institutions affect state behavior and collective outcomes in an issue-area they address? Which factors determine the stability of international regimes?" (Hasenclever et al., 1996, :177). Empirical contributions typically set up the theoretical argument that is derived from one of the mentioned theoretical paradigms and continue with a series of case-studies to either support or modify the derived argumentation (Kydd, 2001; Mitchell and Bernauer, 2004; Morrow, 2001; Oatley, 2001; Pahre, 2001; Richards, 2001; Rosendorff and Milner, 2001; Underdal, 2002; Young, 1993). The publication by Breitmeier et al. (2006) is an exception and offers a medium-n database of 23 regimes that have been coded by experts.

2.2 Uncertainty, Ignorance and Risk

Social science has developed multiple concepts and ideas to describe the unknown. Much work has been done in the field of economics and game theory to model the consequences of 'asymmetric information' or 'incomplete information'. Since these valuable contributions use different concepts of 'uncertainty', this section aims at a minimal definition as basis for this study. To avoid misunderstandings, this section provides a conceptional distinction between 'certainty', 'uncertainty', 'risk' and 'ignorance'.

Knight (1965) contributed one of the most employed concepts of uncertainty within social sciences. He defines uncertainty - in contrast to risk - as a situation where no objective, or publicly verifiable, probability distribution exists. According to this definition, he purposely distinguishes between uncertainty and risk: uncertainty involves only scarce or ambiguous information that does not reveal probability distributions about an outcome. The ambiguous character of information leads to a situation where actors are aware of possible future outcomes, but have no knowledge about the likeliness of a specific future outcome.

Contrasting 'risk' from 'uncertainty' on the grounds of knowledge about probability distributions has proven very helpful in highlighting different implications of risk and uncertainty for social behavior. Both knightian risk as well as knightian uncertainty have *in common* that outcomes of a certain action is not known. They *differ* only with regard to the availability of objective, additive probability distributions. However, characterizing 'uncertainty' merely on the grounds of probability distributions is problematic, because it neglects knowledge about the set of possible outcomes. This makes 'uncertainty' indistinguishable from 'ignorance'. Both 'ignorance' and 'uncertainty' are characterized by the absence of knowledge about a definite outcome and the absence of knowledge about probability distributions. The distinguishing feature that analytically separates uncertainty from ignorance is the knowledge about what outcome *could* possible be the result of a certain action.

The following table shows how considering an additional dimension (knowledge about the set of possible outcomes) sharpens the concept of uncertainty and makes it distinguishable from closely related concepts:

	certainty	*risk*	*uncertainty*	*ignorance*
Definite outcome	Known	Unknown	Unknown	Unknown
Probability distribution	'One'	Known	Unknown	Unknown
Set of possible outcomes	Known	Known	Known	Unknown

Table 2.1: Certainty, Risk and Uncertainty

A simple throw of a dice can serve as an example: In the case of *certainty*, a perfect dice has six sides with the same number; a known outcome will occur with a probability of one[2]. In the case of *risk*, a perfect dice will reveal one outcome out of a known set of outcomes with a known probability, while in the case of *uncertainty* the player does not know whether and to what degree the dice is loaded or not. In a situation of *Ignorance*-situation, the player does not know the specific attributes of the dice, e.g. how many sides the dice has or if it is loaded or not.

The main features of 'uncertainty' have been defined as the absence of knowledge about a definite outcome, the availability of knowledge about the set of possible outcomes and the absence of knowledge about the likeliness of a single, definite outcome. The distinction between 'uncertainty' and 'ignorance' is crucial. Actors faced with 'uncertainty' have (ambiguous) information about the potential consequences of their action which is not the case if they act under 'ignorance'. Beginning from the minimal definition of 'uncertainty', the study of international relations and specifically the study of international regimes has identified different

[2]This, of course, only holds under the assumption that the basic rules of physics (gravity, fraction, etc.) are sufficiently at work and the dice is not hit by lightning

kinds of 'uncertainty' that differ in their source and their implications for social behavior. The next section will show how literature has treated these aspects and what conclusions have been drawn from it.

2.3 Uncertainty in International Relations

> "In particular, governmental policy makers may not perfectly know how the world economic system works. Disagreement could arises not only from a conflict of interest in underlying preferences but from different predictions concerning the consequences of agreement."
>
> Keisuke Iida *Analytic Uncertainty and International Cooperation*

While uncertainty in the form of asymmetric or incomplete information has been a major theme in economics, game theory and decision theory (Alt et al., 1988; De Mesquita et al., 1997; Downs and Rocke, 1990; Fearon, 1997; Morrow, 1989), surprisingly few studies within international relations literature explicitly addresses the issue of uncertainty. Rathbun (2007) shows how uncertainty is an implicit – yet unaddressed – feature of nearly every major theoretical paradigm in international relations study. He exemplifies how four major theoretical paradigms in IR – Realism, Rationalism, Cognitivism and Constructivism – comprise different concepts of uncertainty (Rathbun, 2007, :533). According to him, rationalism treats uncertainty as a pure *lack of information* while cognitivism treats uncertainty as the *ambiguity of information* which leads to confusion (see table 2.2). While for rationalists, the remedy is *updating information*, cognitivists regard *cognitive shortcuts* or *scientific models* as tools to overcome the challenges of uncertainty (Rathbun, 2007, :534). While Rathbun's contribution valuably illuminates an important, yet somehow 'hidden' feature of IR-theory, his view is however slightly misleading since it gives the impression that the same unitary phenomenon (in this case 'uncertainty') is simply regarded through different theoretical lenses (in this case realism, rationalism, cognitivism and social constructivism). Rathbun neglects that uncertainty and its consequences are not just a matter of theoretical conceptionalisation. As argued in subsection 2.2, uncertainty is diverse and comprises different features. While the minimal definition in section 2.2 points out the differences between risk, uncertainty and ignorance, research has shown that a closer focus on the *nature* of uncertainty and its sources reveals new implications. Political game theory proposes that the main source of uncertainty stems from the unknown future behavior of the other actors(s) (McCarty and Meirowitz, 2007). But as studies from macro-economics demonstrate, the mode through which players assess their pay-off functions has significant effects for the cooperative setting. Frankel and Rockett (1988) call this 'model uncertainty' where actors do not know which model reflects reality the best (Ghosh, 1988). Their research shows that expected pay-offs highly depend on the model that is employed to predict future gains from multilateral macroeconomic coordination. Their simulation shows that the choice of a particular model has in some cases more impact on the structure of expected pay-offs than the choice of wether to coordinate action or not.

This notion is picked up by Iida (1993), who argues in favor of a distinction of uncertainty according to its source. His study on macroeconomic cooperation shows how analytic uncertainty – as opposed to strategic uncertainty – changes pay-off functions in a macro-economic coordination game:

> "In particular, governmental policy makers may not perfectly know how the world economic system works. Thus, the economic outcomes of policies are not perfectly predictable. Disagreement could arises not only from a conflict of interest in underlying preferences but from different predictions concerning the consequences of agreement." (Iida, 1993, :433)

Iida (1993) distinguishes *strategic uncertainty* from *analytic uncertainty*; strategic uncertainty evolves from unknown intentions and attributes of the other actors which is the major theme in political game theory and has found its way into the study of international relations. Analytic uncertainty, on the other hand, stems from the complexity of real-world phenomena. Iida states that "...the crucial difference between strategic and analytic uncertainty [...] lies in the fact that players are assumed to know their *own* payoffs perfectly under strategic uncertainty while they may not know their *own* payoffs [...] under analytic uncertainty" (Iida, 1993, :433, emphasis in the original).

Few contributions from environmental economics have included scientific uncertainty into their research by modeling it as a random variable into the welfare-functions (Helm, 1998; Kolstad, 2005, 2007; Kolstad and Ulph, 2011; Na and Shin, 1998). These contribution either highlight the possibility of hiding distributional interests behind "the veil of uncertainty" (Helm, 1998) or model countries as being affected symmetrically by scientific uncertainty (Na and Shin, 1998). Both views do not capture scientific uncertainty comprehensively. A scenario in which countries were able to hide their preferences by pointing to scientific uncertainty indicates that a country can actually assess the distributional effects of a specific outcome. This indicates that scientific uncertainty must have been already reduced at least for a state with the intensions to exploit scientific uncertainty for its own interest. In this case, actors rather strategically hide information to direct the outcome in their interest rather than a case where scientific uncertainty hampers states to set up clear pay-offs. However, if the available information reveals a spectrum of possible pay-offs that can have both a positive or negative sign with unknown probabilities to which direction the pay-off might turn, the possibility of hiding interests is ruled out.

In a recent contribution, Barrett and Dannenberg (2012) pick up the notion of scientific uncertainty and show in an experimental design how scientific uncertainty can change the setting from a prisoners' dilemma into a coordination-game. They subdivide 'scientific uncertainty' into 'uncertainty about thresholds' and 'uncertainty about the resulting effects' from breaching a certain threshold. They show how collective action depends not only on scientific uncertainty as such; rather, their research suggests that different *aspects* of an issue can be affected by scientific uncertainty to varying degrees. This notion will be addressed in section 3.3.

Cognitivist authors incorporate the notion of analytic or scientific uncertainty into their framework by claiming explanatory power for regime formation on policy issues that are plagued by scientific uncertainty. (Haas, 1992a). Cognitivists core assumptions as mentioned in section 2.1 (model dependency, consensuality and epistemic communities) can only be meaningful if scientific knowledge is uncertain, this means if actors anticipate more than one single future outcome. Otherwise, information would speak for itself. The definition of 'the state of nature' would be given and not an issue of discussion and, self-evidently, not an issue that actors have to agree upon before engaging in meaningful discussion. Therefore, scientific uncertainty is a prerequisite for a cognitivist approach to be applied.

Bearing this in mind, decision-makers are portrayed to be unable to adequately formulate interests and struggle to set up pay-off matrices. Cognitivists draw on the literature from psychology in international relations (Goldgeier, 2001; Jervis, 1976; McDermott, 2004; Young and Schafer, 1998) and integrate works on the role of ideas and models in foreign policy (Chwieroth, 2007; Goldstein and Keohane, 1993; Jachtenfuchs, 1995; Lieberman, 2002) which lead cognitivists to three assumptions: First, the demand for international regimes depends on actors perception of international problems, which is, in part, produced by their causal and normative beliefs (Hasenclever et al., 1997, :137). This reveals an additional cooperation dilemma: gains from cooperation are not only jeopardized by possible free-riding or leakage, but actors cannot be sure if these gains exist at all in the first place. Cognitivist contributions emphasize the importance of 'epistemic communities' who inform policy makers. If different plausible models offer divergent conclusions on how to maximize utility, the agreement on one single model is crucial for coordinated action. According to cognitivists, decision makers have to agree on one model before they can engage in a meaningful discussion about the issue at stake and negotiate the terms of an agreement (Dimitrov, 2006).

Table 2.2 summarizes the core features of an interest-based and knowledge-based approach in regime-study:

	Rationalism	*Cognitivism*
Central Explanatory Variable	Interests	Knowledge
Meta-theoretical orientation	Rationalistic	Weakly rationalistic
Perception	Objective	Subjective
Nature of Reality	Objectively real	Subjectively perceived
Nature of Uncertainty	Strategic	Analytic
Quality of Uncertainty	Weak	Strong
Obstacles to Regime-formation	Collective-Action-Dilemmas	Diverging Models of Reality
Problems of Uncertainty	Lack of Information	Ambiguity of Information
Tools for reducing Uncertainty	Updating Information	Cognitive shortcuts and models

Table 2.2: Summarizing Regime Theory

The systematic overview shows the merits and shortcomings of both theoretical approaches on which I will elaborate in detail in 2.4. A general shortcoming is the focus on a rather limited scope of both theoretical strands. Both approaches treat the key features of their theory in an exclusive manner. In this way, they neglect that in many empirical cases for which they claim explanatory value, some key features cannot be separated from each other and exist simultanioulsly. For example, no approach accounts for interaction-effects with a central variable from the other approach. As the next sections will display, an investigation of the interplay between knowledge and interests can be informative. The same accounts for the nature of uncertainty. In more situations, actors do not face either strategic *or* analytical uncertainty, but rather a mix of both. By limiting the scope on only one phenomenon, each strand forfeits explanatory value.

It will be argued in subsection 3.2 that these weak spots can be circumvented and explanatory leverage is gained by integrating both approaches. I argue that despite the displayed differences, both theoretical strands are rather supplemental than contradictory. Calculated in its weakest form as Haas (1992b) and others express it, cognitivism rests on similar (positivist) epistemological and ontological assumptions (Hasenclever et al., 2000, :11) as rationalism. The employment of different central explanatory variables is not an obstacle *per se*. On the contrary, a shift of focus on the interplay of both central variables might reveal new insights on long-standing puzzles.

2.4 Regime Study – Three Objections

The study of international regimes has matured over the past 20 years. It seems as though some shortcomings have sunk in and have been reproduced time and time again. This section elaborates on the theoretical weak spots and it will reveal some shortcomings in commonly employed research designs.

2.4.1 Objection Number 1: Theoretical Segregation

Rationalist approaches have convincingly argued why forming an international regime serves the individual interests of utility-maximizing states. However, these approaches have trouble accounting for scientific uncertainty. The predictions for crop yield changes due to climatic change displayed in figure 2.1 are taken from the assessment report of the International Panel for Climate Change (IPCC). For a country like Mongolia, the report predicts either an increase or a considerable loss in wheat yield due to climate change (IPCC, 2007a). In light of the best information available, Mongolia is still left with the uncertainty whether to favor climate change or not and therefor whether to support international efforts to fight climate change or not.

As previously mentioned, cognitivism considers scientific uncertainty to be a key feature of increased policy issues in a complex world. The underlying core assumption of cognitivist scholars is that in the light of scientific uncertainty, consensually

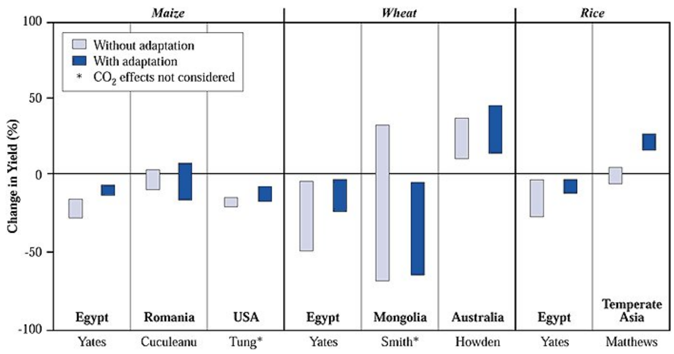


FIGURE 2.1: Wheat Yields Projections

shared knowledge among epistemic communities enhances the chances of a successful regime formation process (Haas, 1992b), meaning that the more scientific elites agree on one model to be the 'true' model, the more probable it is that political decision-makers come to form a regime. Knowledge-based approaches however lack (a) a convincing coherent theoretical base for arguments, (b) neglect strategic effects of scientific uncertainty and vice versa scientific knowledge and (c) frequently fall short in providing empirical evidence for its theoretical predictions. Knowledge-based regime analysis relies on a rather fragile theoretical basis. The underlying idea of knowledge-based approaches is that knowledge shapes the perception of issues and therefore influences states behavior (Hasenclever et al., 1997, :149). On this ground, knowledge-based regime analysis hypothesizes that a shared understanding of consensual knowledge facilitates the regime formation process. However, the causal link between shared knowledge and international cooperation remains rather vague and empirical studies leave us with a contradictory picture.

While Frankel (1988)'s contribution introduces the model-dependency of expected pay-offs to macro-economics, he also finds that gains from cooperation exist *despite* the employment of divergent scientific macroeconomic models. Therefore, from a modeling perspective, a consensually shared perspective among actors is not a necessary condition for actors to expect common gains from cooperation. Furthermore, the contribution of Wettestad (2000) and the contribution of Skodvin (2000) show empirically that international regimes were formed despite divergent causal beliefs. Vice versa, several attempts at international cooperation failed despite consensual knowledge (Helleiner, 2008). It is also questionable if new scientific knowledge necessarily reduces scientific uncertainty and facilitates regime-formation. New scientific findings can easily reveal new and stronger uncertainties or - as Haggard and Simmons argue - "easily might render a game less cooperative by exposing new incentives to defect" (Haggard, 1987, :510). Theoretical considerations as well as empirical findings lead to a rejection of one major claim of knowledge-based regime theory: consensually shared knowledge is neither a necessary nor a sufficient condition for regime-building. The relationship between uncertainty, knowledge, interests and political action seems to be more entangled than previous research suggests.

To assess the role of scientific uncertainty and scientific knowledge in the process of regime formation, it seems more appropriate to focus on the impact of knowledge on the formation of interests rather than establishing a direct link between knowledge and regime formation. The impact of information on the formation of interests is intuitively hard to deny, since interests necessarily rest on some form of causal ideas (see for example Goldstein and Keohane (1993)). Within a rationalistic framework, it is hard to think of anything else but ideas and models about mechanisms in the real world as a base for formulating preferences and interests. Even though several authors articulate the need for an integration of knowledge-based and interest-based assumptions, (Hasenclever et al., 2000) literature lacks a coherent theoretical model. Section 3 aims at filling this gap and will for that purpose examine more closely how scientific knowledge can influence actors' interests. Furthermore, it will shed light on the relationship between uncertainty, new scientific knowledge, interests and policy.

2.4.2 Objection Number 2: No Variance on the Dependent Variable

Empirical studies in the field of regime study have primarily been conducted through small-n comparative case studies in which the evolutionary process of existing regimes are retraced. With few exceptions (for example Dimitrov (2006)), these studies examine exclusively successful cases of regime formation processes with the intension to trace causal inference of factors that lead to regime formation. However, by omitting stalled regime formation processes as cases (or 'Non-regimes' as Dimitrov (2006) calls it), regime study faces problems claiming causal inference as it lacks a comparative dimension.

When regime study omits 'stalled regimes' or 'non-regimes' (Dimitrov et al., 2007), it ignores control cases that are crucial for testing causal hypothesis. Such a research design implicitly assume that the absence of the factor that lead to regime formation in the examined case(s) would automatically lead to a failure of regime formation. Case selection, then, is biased towards a selection on the dependent variable (Geddes, 2003) and does not cover all possible values of the dependent variable and - as articulated by Arild Underdal - "...the entire field of regime analysis is biased in favor of positive findings" (Underdal, 2002, :447).

2.4.3 Objection Number 3: Flawed Conceptionalization of Scientific Knowledge as Independent Variable

The third objection concerns the conceptionalization of 'knowledge' as independent variable by cognitivist scholars. The explanatory value of scientific knowledge is (a) not convincing as it has different implications for different actors and (b) has so far not been operationalized sufficiently. As Dimitrov et al. (2007) states, "[T]he [...] problem with knowledge-based accounts of international environmental policy is that, strictly speaking, there are none. All cognitivist explanations focus on factors other than the available information per se: actors, institutions or processes." (Dimitrov et al., 2007, :30). As mentioned in section 2.1, the independent variable 'knowledge' can - broadly speaking - either occur as 'consensually shared' or 'not shared'. This conceptionalization, however, neglects the actual *contents* of 'knowledge'. If, for example, epistemic communities and policy-makers consensually agree that something is *not* a threat to human health, cognitivist considerations would still leave us to expect a successful regime-formation while, at the same time, the actual reason for forming a regime (escaping a collective-action-dilemmas to realize gains from cooperation) would not be given. Consensually shared knowledge is therefore not sufficient. Within a cognitivist framework, at least two conditions have to be met: First of all, knowledge has to be consensually shared by relevant actors and secondly, the knowledge has to provide a reason for forming a regime. Dimitrov (2006) addresses this shortcoming by disaggregating knowledge into three sectors: (a) knowledge about the extent, (b) knowledge about the causes of a problem and (c) knowledge about consequences to human society (Dimitrov, 2006, :34). By this nature, a research design that investigates the impact of knowledge on regime-formation is considerably improved. As subsection 4.4.1 will show, it makes however sense to disaggregate knowledge further.

2.5 Summary: Defining Scientific Uncertainty

> "Scientific uncertainty is a fact of life and many toxic substances issues present the choice between two risks: the risk of economic and other costs without corresponding benefits and the risk of irreversible damage to health and the environment if the substance turns out to be harmful."
>
> Thomas B. Stoel et al.*Flourocarbon Regulation*

Starting with a review of the literature on international regimes and literature on uncertainty, the preceding chapter shows how the concept of uncertainty is either implicitly or explicitly woven into the literature on international relations as well as on international regimes. This chapter, however, argues in favor of a more clear-cut definition of uncertainty which leads to a better understanding of scientific uncertainty: First of all, considering knowledge about the set of possible outcomes allows to distinguish uncertainty from ignorance. Secondly, it has been argued in line with Iida (1993) that uncertainty has to be differentiated according to its source. Both concepts allow us to arrive at a more comprehensive concept: scientific uncertainty can be defined as knowledge about a set of possible outcomes (in contrast to knowledge about a specific outcome (certainty) or no knowledge about any future outcomes (ignorance)) with unknown probability distributions due to ambiguous scientific knowledge. The absence of definite knowledge about pay-offs distinguishes scientific uncertainty from strategic uncertainty.

Furthermore, this chapter takes a critical stance on regime study. It argues that regime study suffers from three shortcomings. First of all, regime study systematically neglects control cases of regime formation processes that did or do not lead to a formalized international regime. The focus on small-n studies of successful regime formation processes limits conclusions on causal factors for regime formation. Secondly, knowledge-based regime study suffers from (a) an unconvincing theoretical framework and (b) an inconclusive conceptualization of 'knowledge' as an independent variable. The next chapter argues that an appreciation of the *content* of knowledge promises insights on the puzzling effects of scientific knowledge on regime formation. And (c), current regime theory either neglects scientific uncertainty (as in rationalist approaches) or conceptionalizes it unconvincingly (as in cognitivist approaches).

Even though some authors have called for an integrated theoretical framework (Hasenclever et al., 2000), a more nuanced appreciation of knowledge in the context of regime study (Dimitrov, 2006; Sprinz and Vaahtoranta, 1994) and an integration of failed regimes as cases (Underdal, 2002), literature on the issues is scarce. The next chapter (chapter 3 aims at closing the theoretical gap and intends to develop a coherent theoretical framework. Chapter 4 will pick up the shortcomings in empirical research design by both disaggregating knowledge and integrating failed regime formation processes.

Chapter 3

The Argument: A Theoretical Synthesis

> "Although each theory satisfactorily explains a part of the origin of multilateral environmental cooperation, all need to be invoked to explain the full range of outcomes"
>
> Peter M. Haas *Stratospheric Ozoze: Regime Formation in Stages*

The review of the literature in the previous chapter shows that the two theoretical approaches (interest-based and knowledge-based) which are predominantly employed in the study of international environmental regimes both have their merits and their shortcomings. The aim of this chapter is to integrate these approaches to establish a coherent theoretical framework that appreciates both interests *and* knowledge. The main argument of this work is that empirical results are too puzzling to support the claim that scientific knowledge as such influences regime formation. On the other hand, the informational basis on some environmental issues is too fragile to apply a purely rationalistic framework. To gain insights on the interplay between scientific uncertainty, new scientific knowledge and political action towards regime formation, it is useful to focus on the micro-mechanism of how scientific uncertainty frames the perception of the issue.

This study focuses on multilateral environmental agreements that intend to solve a transboundary environmental issue and potentially would have an effect on the issue through providing a collective good that (Underdal, 2002). The theoretical argument presented here is based on fundamental rationalistic assumptions about international cooperation (Axelrod and Hamilton, 1984; Keohane, 1984; Koremenos, 2005; Moravcsik, 2000; Snidal, 1985): Self-interested states are considered to be the main actors in an anarchic international order in which actors attempt to maximize their own utility. Multilateral environmental agreements are considered to be installed with the intent to resolve collective action problems and serve as means for states to maximize individual utility. However, as argued in the previous chapter, individual gains from cooperation on environmental issues are often more difficult to identify, since environmental issues are often plagued by scientific uncertainty.

The argument in this chapter begins with a micro-level-explanation of individual state interests with no scientific uncertainty (see section 3.1). In a second step (section 3.2), the approach will be transferred to the macro-level of international regime formation to hypothesize on how different configurations of individual state interests increase or decrease the likeliness of international regime formations. In a third step (section 3.3), scientific uncertainty is introduced at a micro-level to theorize on how scientific uncertainty effects the formation of individual state interests. These considerations are transferred as a last step (section 3.4) to the macro level of international regime formation. The aim is to come from the micro level of individual state interests without scientific uncertainty to the macro level of international regime formation with scientific uncertainty. This procedure allows one eventually to arrive at a set of clear-cut and sound hypotheses on the influence of scientific uncertainty and new scientific knowledge.

This eventually allows one to reconsider the role of new scientific knowledge in the process of regime formation (section 3.4). It is argued that new scientific knowledge does not simply facilitate international regime formation. Rather, as the argumentation in section 3.5 shows, the role of scientific knowledge has to be considered more diversely.

3.1 An Interest-based Approach

Whereas individual interests of rational, egoistic states have been at the center of power-based explanations (such as the 'Hegemonic Stability Theory' (Kennedy, 2010; Kindleberger, 1986) or '(Neo-) Realism'), interest-based theories (such as 'Contractualism' (Axelrod and Hamilton, 1984) or 'Institutionalism (Keohane, 1989, 1984)) have dominated the theoretical discussion on international cooperation ever since pure hegemony gradually began to vanish from international relations. However, even though interest-based theories offer coherent explanations as to why states do not cooperate despite common interests and how institutions and international regimes can help to overcome these collective-action problems in the absence of hegemony, they fall short in providing clear observables with regard to when and how regimes form and how interests have to be structured so that states actually form an international regime. The contributions from Sprinz and Vaahtoranta (1994) and Barrett (2001) can be employed to fill this gap. Barrett (2001) makes a clear case by showing that sovereign states cannot be forced into an international regime and argues that if states do not share similar interests, a regime will only form if dissimilarities are overcome through side-payments, package deals or institutional bargaining (Young, 1989). Sprinz and Vaahtoranta (1994) focus on 'interests' as the dependent variable and conceptionalize them as a function of costs and benefits that lead states to either support or not support regime formation. This section shows how both approaches can be employed to link cost-benefit-configurations of individual states to the international level of regime formation.

Sprinz and Vaahtoranta (1994) consider 'interests' as an aggregate of 'costs' and 'benefits' and focus on the individual configuration of 'costs' and 'benefits' to estimate a state's attitude towards institutionalized cooperation. This follows a straight-forward logic: A state will push for international regulation if benefits exceed costs and vice versa. If 'cost' and 'benefits' are either both 'high' or both 'low', states are rather ambivalent towards regulation. Hence, Sprinz and Vaahtoranta (1994) classify them as 'intermediates' or 'bystanders'. According to Sprinz and

Vaahtoranta (1994), the configuration of costs and benefits shapes state's attitudes towards institutionalized cooperation as displayed in table 3.1.

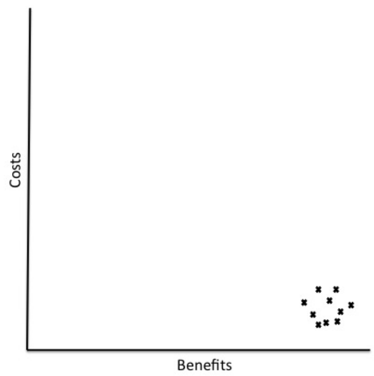
		Benefits	
		low	high
Costs	low	bystanders	pushers
	high	draggers	intermediates

TABLE 3.1: Classification of a Country's Support for International Environmental Regulation (Sprinz and Vaahtoranta, 1994, :81)

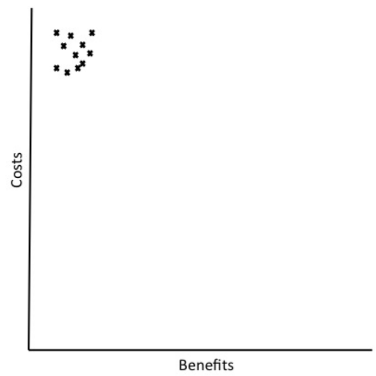
This classification displays a country's expected attitude towards regime formation within a rationalist, interest-based framework. Sprinz and Vaahtoranta (1994) hypothesize that *if a state expects high benefits and low costs, it will push for an international regime* and *if a state expects low benefits and high costs, it will drag efforts towards international regime formation.*

3.2 State Interests and International Regime - Formation

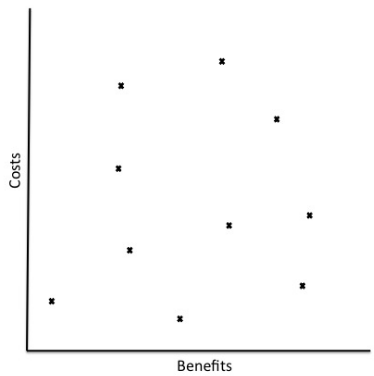
While the concept of Sprinz and Vaahtoranta (1994) sheds light on the mostly neglected 'true nature' of interests, it cannot (nor does it intend to) explain the success or failure of regime formation among multiple states. This section intends to aggregate from the level of individual states interests to the international level of regime formation. For this purpose, the concept of Sprinz and Vaahtoranta (1994) will be extended to include the assumption of similarity (or 'symmetry' as Barrett (1994) calls it) of interests between multiple states. Additionally, the variables 'costs' and 'benefits' will be conceptualized as gradual rather than binary variables. This corresponds more to the way Barrett (2001) theorizes about international environmental agreements. He models the interests of multiple states as either similar and conducive (see figure 3.1(a)) or similar and obstructive (see figure 3.1(b)) in terms of regime formation. Additionally, states can also have dissimilar interests (see figure 3.1(c)). His main argument is that only under the condition of similar and conducive interests, sovereign states will commit to an international regime.



(a) Similar Conducive Interests



(b) Similar Obstructive Interests



(c) Dissimilar Interests

FIGURE 3.1: Symmetry and Asymmetry
Each point represents the perceived costs and benefits of single (fictitious) country.

While Sprinz and Vaahtoranta (1994)'s intend is to explain individual attitudes of involved states towards international regime formation for individual states, Barrett (2001)'s concept allows one to conclude from a macro-perspective in what situations different states have an incentive to form a regime (figure 3.1(a)), when not (figure 3.1(b)) and when states' interests towards regime-formation are not similar (figure 3.1(c)). Both concepts are therefore complementary and can be summarized in the following hypotheses: *if all states are pushers, a successful regime-formation process is more likely* and vice versa *if all states are draggers, a regime-formation process is less likely.* This is reflected in table 3.2, which displays different configurations of 'costs' and 'benefits' for similar states and their implications for regime formation at the international level.

		Benefits	
		low	high
Costs	low	in-between	obstructive
	high	conducive	in-between

TABLE 3.2: Conducive and Obstructive Configurations of Interests when States are Similar

Barrett (2001)'s approach covers multiple states. He argues that in the case of dissimilarity (or 'asymmetry' as Barrett (2001) calls it), institutionalized cooperation can only be 'bought' through side-payments or package-deals. Therefore, *if some states are pushers and some are draggers or in between, a successful regime formation process is only likely if pushers can turn draggers, intermediates or bystanders into pushers.*

However, side-payments and package-deals among states might not be the only means through which conducive similarity (or 'symmetry') can be installed. Realists would argue that hegemonic power could have the same effect. An actor (or a group of actors) that hold the preponderance of power resources relevant to a particular issue area can coerce other actors into participation if it serves its (or their) interests (Keohane, 1982; Kindleberger, 1986; Olson, 1965; Strange, 1982). This does not contradict Barrett (2001)'s argument that sovereign states cannot be forced into a regime. The exertion of power does not *force* states into a regime. It simply changes their cost-benefit-configuration through the pending threat of additional costs for not joining a regime that a powerful actor (or group of actors) wants to install. This additional mechanism through which similarity in interests can be installed has not been considered by Barrett (2001), but perfectly fits into his line of argumentation. This mechanism can of course only work if at least one state is willing and able to bear the costs to turn other states into pushers.

While the contribution of Sprinz and Vaahtoranta (1994) is a useful way to theorize on how individual states form their specific interests, it cannot estimate conditions under which multiple states form international regimes. Barrett (2001)'s model, on the other hand, can explain when states with individual interests have an incentive to form an international regime, but neglects what determines the interests of individual states. Both views are therefore complementary: Sprinz and Vaahtoranta (1994)'s approach can be used as a micro-foundation for Barrett (2001)'s macro-model.

3.3 State Interests and Scientific Uncertainty

The previous section links 'cost' and 'benefits' of individual states to the international level of regime formation by integrating the contribution of Sprinz and Vaahtoranta (1994) and Barrett (2001). This section introduces the concept of scientific uncertainty at the individual state level and theorizes on how scientific uncertainty effects individual states' interests.

Chapter 2 argues that scientific uncertainty and scientific knowledge should not be treated as a unitary phenomenon. Rather, the specific implications of the *content* of scientific knowledge provide insights on its effect on regime formation. With reference to Sprinz and Vaahtoranta (1994)'s concept of interests as being an aggregate of 'cost' and 'benefits', it can be argued that the individual perception of both parameters is shaped by scientific knowledge (Goldgeier, 2001; Levy, 1992; McDermott, 2004). Hence, an argument about the impact of scientific knowledge and scientific uncertainty on regime formation has to acknowledge the impact of scientific knowledge and scientific uncertainty on both the parameters 'costs' and 'benefits'. This eventually provides a micro foundation for the link between scientific uncertainty and regime formation.

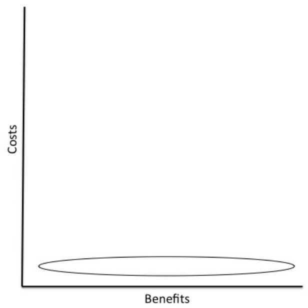
The central argument in this contribution is based on the assumption that scientific uncertainty ought to be considered not as a unitary phenomenon, but as a factor that changes the calculation of the parameters 'costs' and 'benefits' for individual states. While in the framework of Sprinz and Vaahtoranta (1994) 'cost' and 'benefits' can take the values 'high' and 'low' respectively, both parameters can also take the value 'uncertain' on issues that are characterized by scientific uncertainty. Therefore, the parameters 'costs' and 'benefits' can theoretically take three values: high, low or uncertain. If a parameter takes the value *uncertain*, states do not know whether it is 'truely' high or low. Both parameters should be taken in conjunction.

To draw conclusions on the effect of scientific uncertainty on regime formation, it is helpful to consider the effects for a single state first. This allows one to theorize on different configurations of 'costs' and 'benefits' when one parameter is uncertain and the other is high or low, respectively. Secondly, it allows one to theorize about the case when both parameters are scientifically uncertain.

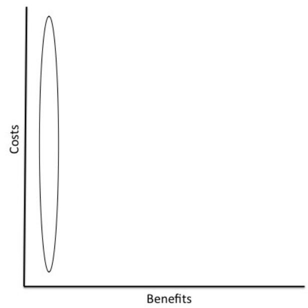
The configurations under ideal-typical conditions are graphically displayed in figure 3.2. It shows five possible configurations:

1. low cost / uncertain benefits (figure 3.2(a))
2. uncertain costs / low benefits (figure 3.2(b))
3. high costs / uncertain benefits (figure 3.2(c))
4. uncertain costs / high benefits (figure 3.2(d))
5. uncertain costs / uncertain benefits (figure 3.2(e))

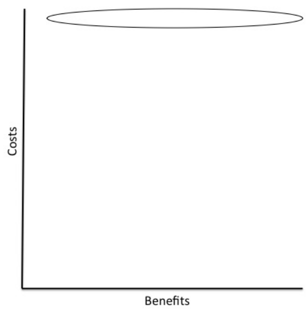
Ideal type 1 in figure 3.2(a) represents a case in which a single state expects low costs from forming a regime while benefits are uncertain. Since costs are expected to be low, a state facing a configuration of 'low costs' and 'uncertain benefits' will rather push for a regime to form. The known set of possible future outcomes



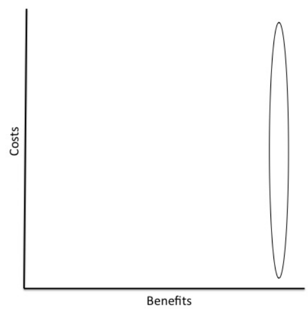
(a) Ideal Type 1



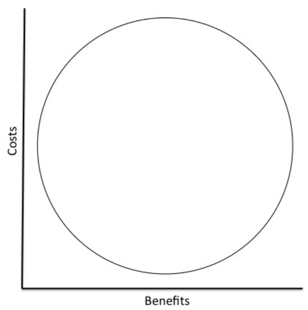
(b) Ideal Type 2



(c) Ideal Type 3



(d) Ideal Type 4



(e) Ideal Type 5

FIGURE 3.2: Ideal Types

indicates that benefits – in the best case – exceed costs or – in the worst case – merely balance each other out. Regardless of the 'true' outcome, it can be plausibly reasoned that a state will rather 'push' for multilateral regulation. This allows one in a first step to hypothesize about its support for international institutionalized cooperation. *If a state expects low costs and uncertain benefits, it will push for an* *international regime.*

However, a state might find itself in a position where costs are uncertain while benefits are low (see ideal type 2 in figure 3.2(b)). In this case, a state expects to benefit only little while it potentially faces high costs. Facing this configuration, a state can be assumed to 'drag' regime formation since the configuration of scientific knowledge leads it to expect potentially high costs and certainly low benefits. In the best case, a state achieves low benefits at low costs. In the worst case, it faces low benefits at high costs. Hence, *if a state expects uncertain costs and low benefits, it will drag a regime formation process.*

Ideal type 3 and 4 (figures 3.2(c) and 3.2(d)) are in between and correspond to what Sprinz and Vaahtoranta (1994) would call 'intermediate' or 'bystanders'. Even though less clear-cut, it can be argued that states are more positive towards international regulation if there is a possible future outcome within the set of possible future outcomes where high benefits can be achieved at low cost. This is the case in ideal type 3 (figure 3.2(c)). Vice versa, when the best possible future outcome within the set of possible future outcomes predicts high benefits to high costs while in the worst possible outcome only low benefits are achieved at high costs (ideal type 4 in figure 3.2(d)), states can be assumed to be less favorable towards institutionalized cooperation. Therefore, while both ideal types are less clear-cut, it can be plausibly argued that ideal type 3 (figure 3.2(c)) is more conducive in terms of institutionalized international cooperation than ideal type 4 (figure 3.2(d)).

If both costs and benefits are affected by scientific uncertainty, hypothesizing about support of international regime formation is the least clear-cut. Any conclusions on how a state anticipates its costs and benefits remains speculative. If a state – as in ideal type five – does not have any information about the outcome of their decision on institutionalized cooperation, they can not anticipate whether they would gain or loose from cooperation. However, there is a plausible argument that a state will most likely invest (either politically or economically) in new scientific knowledge to reduce the uncertainty and assess a clearer picture of costs and benefits. Therefore, one can expect that *when being confronted with a configuration of uncertain costs and uncertain benefits, a state will intensify its research efforts.*

The considerations allow one to hypothesize about the expected level of support towards international regime formation for individual states with and without scientific uncertainty (see table 3.3). This classification is based on Sprinz and Vaahtoranta (1994) with the additional dimension of uncertainty and a modification of labels to account for additional classifications. It seems still plausible that the clearest and strongest support or opposition can still be expected in the scenarios without scientific uncertainty. In these scenarios, states can clearly identify if benefits exceed costs or vice versa and will either strongly push or strongly drag a regime formation process. As examplified in the previous section, in some scenarios *with* scientific uncertainty, states can be expected to rather push or rather drag. To introduce a more gradated classification that accounts for scenarios with scientific uncertainty, 'pushers' in the original are relabeled 'strong pushers' and 'draggers' are relabeled 'strong draggers'. This serves the sole purpose of introducing a more fine-grained relational classification.

		Benefits		
		low	uncertain	high
Costs	low	in-between	pusher	strong pusher
	uncertain	dragger	call for more research	pusher
	high	strong dragger	dragger	in-between

Table 3.3: Country's support for international environmental regulation with scientific uncertainty

The strongest support can still be expected from countries that expect high benefits at low costs and the strongest resentments can still be expected to be expressed by countries expecting low benefits to high costs. However, countries that face scientific uncertainty might be more easily turned in a certain direction, a fact that will be picked up in the next section.

3.4 State Interests, Scientific Uncertainty and International Regime Formation

Exemplifying how individual state interests emerge (section 3.1), what configuration of state interests are more or less conducive in terms of international regime formation (section 3.2) and how scientific uncertainty impacts on individual state's interests (section 3.4) paved the way to argue in this section how scientific uncertainty influences international regime formation. This section starts with the assumption of multiple states with similar interests towards regime formation and scientific uncertainty to draw hypotheses about successful or unsuccessful regime formation. In a second step, the assumption of similarity is relaxed to draw hypotheses on the empirically more plausible case of dissimilar states.

On an individual state level, scientific uncertainty adds additional configurations of costs and benefits, some of them lead a state to (weakly) push for international regime formation, some of them lead a state to (weakly) drag a regime formation process. In one configuration, a state can simply be expected to conduct more research before choosing a course of action. In a next step, the insights on expected level of support of single states can be aggregated to the international level of international regime formation by assuming similarity and theorizing on what configurations would be conducive or obstructive in terms of regime formation. Table 3.4 corresponds to table 3.3 in the previous section, but it displays the view of multiple states rather than a single state.

		Benefits		
		low	uncertain	high
Costs	low	intermediate	conducive *IV*	strongly conducive
	uncertain	obstructive *I*	conducive for the coordination of research efforts *V*	non-obstructive *III*
	high	strongly obstructive	non-conducive *II*	intermediate

TABLE 3.4: Classification of configurations of multiple states with similar interests under the condition of scientific uncertainty

As the parcels without scientific uncertainty (the grey-shaded parcels) have been discussed at length by Sprinz and Vaahtoranta (1994) and in the previous sections of this chapter, the following exemplifications focus on the configurations with scientific uncertainty.

In terms of regime formation, a configuration where costs are uncertain and benefits are low (parcel I) can be considered as being 'obstructive', since anticipate that the best outcome would be to realize low benefits at low costs, while at worst, they realize low benefits and face high costs. A scenario where costs are high and benefits are uncertain (parcel II) can be considered to be 'not conducive', since states anticipate that the best possible outcome would entail high benefits at high costs, while the worst outcome would entail low benefits at high costs.

In contrast, the configuration where costs are uncertain and benefits are high (parcel III) can be considered to be at least 'not obstructive', because state anticipate that their benefits are high and costs can turn out to be either low (which would turn them into pushers) or high (which would turn them into intermediates). The most conducive configuration in an scenario with scientific uncertainty is a configuration where costs are considered to be low while benefits are uncertain (parcel

IV). In this case, the worst outcome for states would be a situation where they would face low benefits at low costs. On the other hand, there is a chance for states to realize high benefits at low costs.

A scenario where both costs and benefits are scientifically uncertain (parcel V) can be considered to facilitate the exchange of research and the coordination of research efforts. It is plausible to assume that states which face scientific uncertainty on both dimensions have a rational interest in updating their information and in internationally coordinating the exchange of information and scientific research.

The considerations of the previous sections have so far (a) shown how scientific uncertainty affects individual state interests and (b) how individual interests affect success or failure of a regime formation process. This allows to draw the following set of hypotheses:

Under the condition of all other factors being equal (ceteris paribus),

H 1a: if the profile of scientific uncertainty is conducive, states are more likely to behave as pushers and a regime formation process is more likely to be completed

and, vice versa,

H 1b: if the profile of scientific uncertainty is obstructive, states are more likely to behave as draggers and a regime formation process is more likely to stall.

This argumentation only holds for the condition of similarity between states, meaning that all states share a similar configuration of interests. If this assumption is relaxed, Barrett (2001) shows how cooperation can be 'bought' by states with a conducive configuration. The existence of at least one state with a conducive[1] configuration that has the willingness and means to buy cooperation through side-payments, compensations or package deals is a prerequisite for a regime to form.

[1] I exclude configurations without scientific uncertainty for the same reasons I stated above. There is an argument, though, that in some cases, scientific uncertainty might blur asymmetry and that therefore, scenarios with scientific uncertainty might in some cases be superior to scenarios without scientific uncertainty.

Side-payments, compensations and package-deals can eventually resolve asymmetry by altering the configuration of states with a 'weakly conducive', 'weakly obstructive' or even 'obstructive' configuration to a 'conducive' one. It is plausible to argue that states with a weakly conducive configuration can be more easily bought into cooperation than states with a weakly obstructive configuration. States with an obstructive configurations require the most to be turned.

On the international level, scientific uncertainty can also blur dissimilarities between states. While section 3.2 identified with reference to Barrett (2001) two mechanisms that can change dissimilarities between states (side-payments by other states or coercion by a powerful hegemon), scientific uncertainty can have similar effect.

3.5 The Role of Scientific Uncertainty and New Scientific Knowledge

Conceptionalizing scientific uncertainty as a factor that shapes the perception of costs and benefits also allows one to rethink the role of new scientific knowledge as well. As noted in subsection 2.4, the cognitivist claim that new scientific knowledge *per se* facilitates regime formation as such does not seem plausible. As in the case of scientific uncertainty, it is more informative to consider the content of new scientific knowledge and its consequences rather than its mere presence (Sprinz and Vaahtoranta, 1994).

Ideally, scientific knowledge reduces scientific uncertainty to zero. Nevertheless, new scientific knowledge can easily increase scientific uncertainty. Plausibly, new scientific findings can reveal flaws and imprecision in previous research and thus reveal what areas are still unknown. Hence, new scientific knowledge can either (a) reduce uncertainty, (b) reveal new gaps in existing knowledge and thereby increase scientific uncertainty or (c) change the body of scientific knowledge without enhancing or reducing it.

Scientific knowledge does not enhance the chances for regime formation per se, nor does it facilitate agreement among scientific elites. As in the case of scientific uncertainty, it is instead the specific content of new knowledge and its effect on the assessments of the situation by different actors that have an impact on regime formation. It can be assumed that the effect of new scientific knowledge can go both ways, it can either convert a configuration of costs and benefits from obstructive to conducive (or vice versa). Therefore it can be hypothesized:

H 2: A successful regime formation process is more likely if new scientific knowledge modifies the profile of scientic knowledge towards a pushing profile.

New scientific knowledge *only* enhances the chances of a successful regime formation process in the following scenarios: (a) A disfavorable setting as articulated in figure 3.2(b) is turned through new scientific advances into a more favorable one as displayed in figure 3.2(a). (b) Scientific uncertainty is completely ruled out through new scientific advances *and* the new cost-benefit-structure converges into a symmetrical setting as displayed in figure 3.1(a).

3.6 Summary

The theoretical framework advanced in this chapter aggregates the interest-based approach by Sprinz and Vaahtoranta (1994) from the individual level of states' interests to the international macro level through the integration of Barrett (2001)'s approach of symmetry. This allows one to advance from hypotheses on individual behavior to hypotheses about whether a regime is more or less likely to form. Both steps are necessary to coherently integrate scientific uncertainty and account for asymmetry: First, scientific uncertainty is integrated into the interest-based approach to theorize about how states' interests are altered under the condition of scientific uncertainty. It turns out that scientific uncertainty adds five additional patterns of expected attitudes: two with a tendency to create additional pushers, two with a tendency to create additional draggers. In one configuration, states can be expected to have a neither supporting nor dragging attitude, but simply invest in more research.

The state-level framework *with* scientific uncertainty can be aggregated to the international level to arrive at hypotheses on regime-formation under the condition of scientific uncertainty. The logic is similar to the approach of aggregating from an individual level (Sprinz and Vaahtoranta, 1994) to an international level *without* scientific uncertainty: assuming symmetry allows one to hypothesize about which configurations of costs and benefits are rather conducive or obstructive in terms of regime formation. As shown in the individual-state-approach, scientific uncertainty adds additional configurations of costs and benefits: two being rather conducive, two being rather obstructive and one configuration under which states can be expected to coordinate their research efforts in order to be able to better define their configuration of costs and benefits.

The theoretical considerations also allow one to hypothesize about how states deal with dissimilarities (or asymmetry) under the condition of scientific uncertainty. Since scientific uncertainty simply adds additional configurations of cost and benefits, it can be expected that similar mechanisms will be observable as in the case without scientific uncertainty: In the case of dissimilarity and scientific uncertainty, states with a conducive configuration can be expected to attempt to turn other states into pushers, either through side-payments or coercion. However, as exemplified in section 3.3, scientific uncertainty might blur dissimilarities between states. In that case, cooperation can be bought more easily from pushers as compared to a scenario without scientific uncertainty.

The theoretical considerations on scientific uncertainty furthermore allowed to plausibly reason under which condition new scientific knowledge becomes conducive or obstructive for regime formation. New scientific knowledge simply reshapes the configurations of costs and benefits by providing new information along either dimension.

Chapter 4

Research Strategy and Research Design

> "There is growing consensus that the strongest means of drawing inference from case studies is the use of a combination of within-cases analysis and cross-case analysis."
>
> Alexander L. George and Andrew Bennett
> Case Studies and Theory Developement

In chapter 2 and 3, a clear case is made for the need of structured research on international regime formation under the condition of scientific uncertainty. Why do some international regimes form while others stall in the process? This chapter will present the research strategy and the research design for the empirical analysis. More specifically, the chapter will illustrate 'hows and whys' of the empirical analysis. It will explain the choices for cases, strategies and methods.

The complexity of the theoretical argument leads to the choice of a comparative qualitative design, the rationales for this choice are discussed in section 4.1. The theoretical argument also curtails of the universe of cases and the selection strategy (section 4.3). On this basis, section 4.3.1 provides a brief overview on the selected empirical cases that are the best fit for testing the argument. The selected cases cover different international environmental issues: the protection of the stratospheric ozone layer, the international regulation of Persistent Organic Pollutants, the missing international regime on Arctic haze and the missing international regime on global deforestation.

Since the theoretical argument defines the configuration of scientific knowledge as the independent variable and the regime formation process as the dependent variable, both are operationalized in section 4.4.1. The Database and the methods for data selection are introduced in section 4.5.

4.1 Testing the Hypotheses: A Qualitative Design

The main interest of this study is a better understanding of the interplay between scientific knowledge and regime formation on issues that involve scientific uncertainty. The argument as stated in chapter 3 is based on the assumption that the content of knowledge (independent variable) affects a regime formation process (dependent variable) through framing actors' cost-benefit-calculations. Scientific uncertainty leaves actors with science-based knowledge about a *set* of possible future outcomes rather than only one single expected future outcome (see section 2.2 and chapter 3). It has been argued in the previous sections that this *set* can be conceptualized as a specific configuration of scientific knowledge which is either conducive or obstructive in terms of regime-formation. A conducive profile in this context refers to a profile where costs are determinably low while benefits are uncertain. From an actor's perspective, benefits in a conducive profile can turn out to be either high *or* low, while costs are expected to be certainly low. The profile is conducive because actors expect the gains from forming a regime to be $\geq$ zero[1]. The opposite holds for an obstructive profile of scientific knowledge: An obstructive profile refers to a profile where expected benefits are determinably low while costs are uncertain. Costs can be either high *or* low, while benefits are

[1]For simplification, costs are assumed to be zero in this example.

certainly low. It is obstructive since actors can expect gains from forming a regime to be ≤ zero.

Costs & Benefits

Costs and benefits result from a particular action (Hanley et al., 2009), in this case contracting an international regime. This rests on the assumption that costs and benefits are only realized through institutionalized cooperative action as argued in chapter 3. Both are considered as 'social costs and benefits', that is the costs and benefits to all members of a society in a nation state (Hanley et al., 2009). In this study, costs are conceptualized as direct costs from abatement (Sprinz and Vaahtoranta, 1994) such as installing filters, investing in research of subsidies or higher production costs of subsidies. Benefits are conceptionaized as reduced vulnerability, such as diminishing negative human health effects. Since both are case-specific, they are to be operationalized individually from case to case.

Under the condition of scientific uncertainty, hypotheses 1 and 2 state that

H 1a: If the profile of scientific knowledge is conducive, states are more likely to become 'pushers' and a regime formation process is more likely to be completed.

H 1b: If the profile of scientific knowledge is obstructive, states are more likely to become 'draggers' and a regime formation process is more likely to stall.

Hypothesis 1a is supported if the configuration of scientific knowledge is observably conducive and an international regime is formed. Hypothesis 1b is supported if an obstructive configuration is observable and a regime formation process stalls. Vice versa, the argument remains unsupported if the profile of scientific uncertainty is conducive while a regime formation process stalls, or an international regime is formed despite an obstructive profile.

In the context of hypothesis 1a and 1b, scientific knowledge is considered merely as a fixed parameter. It is empirically not plausible to assume that over the course of a regime formation process, the body of scientific knowledge does not change. Rather, it can reasonably be assumed that further research changes the body of scientific knowledge and hence, the basis for cost-benefit calculations. An observable change in the scientific configuration (from obstructive to conducive) that correlates with an observable change in the outcome (from stalled regime to complete regime formation) strengthens the link between both variables.

This is directly addressed through Hypothesis 2:

H 2: A successful regime formation process is more likely if new scientific knowledge modifies the profile of scientific knowledge towards a conducive profile.

The argument is supported for hypothesis 2 if the configuration of scientific nowledge changes through scientific advancement from 'obstructive' to 'conducive' and consequently a regime is formed. The argument is supported as well if scientific advances change the profile of scientific knowledge from 'conducive' into 'obstructive' and a regime formation process stalls. The argument remains unsupported if scientific advances change the configuration of scientific knowledge from 'obstructive' to 'conducive' and a regime formation process *still* stalls or if a regime forms even though new scientific advances turn a 'conducive' configuration into a 'obstructive' configuration and a regime still forms.

Testing the hypotheses requires a sound knowledge about the configuration of scientific knowledge. Profiling scientific knowledge requires a fine-grained understanding of the scientific facts that were present throughout the regime-formation process. An in-depth understanding is necessary to determine what dimension of a cost-benefit analysis was affected by scientific uncertainty, i.e. how the set of possible future outcomes was structured. Since the argument states that actors are more tolerant towards scientific uncertainty if it affects only benefits while, at the same time, costs are expected to be low, it is necessary to analyze what dimension of a cost benefit calculation is uncertain. Testing hypothesis 2 additionally requires tracing changes in scientific knowledge over time and the co-evolution of political action. It is further argued in section 4.2 that hypotheses 1a and 1b are best tested through a cross case comparison whereas hypothesis 2 requires a longitudinal perspective where the impacts of scientific advances on political action are carefully retraced.

Turning to the dependent variable, testing the argument requires a clear-cut analytical separation of a successful regime formation process from a stalled regime formation process. This consequentially requires retracing this process carefully since, as subsection 4.4.2 will show, identifying a stalled regime formation process poses a challenge. Additionally, preferably all alternative explanations as they are proposed by the vast literature on international regimes have to be considered. Though most of the literature does not explicitly consider scientific uncertainty nor stalled international regimes, it cannot be assumed that alternative mechanisms do not play a role.

4.2 Cross-Case Comparison and Within-Case Analysis

Designing this study as a qualitative small-n study follows the conceptualization of both the independent variable as well as the dependent variable. According to George and Bennett (2005), the strength of case study methods are high conceptual validity, their potential to closely examine causal mechanisms and their capacity for adressing causal complexity. All these advantages speak in favor for employing a small-n case-study design in this study. The concept of scientific uncertainty and is difficult to measure in a large sample without over-stretching the concept (George and Bennett, 2005) or without forfeiting too much informational content (Opp, 1970). The limited number of cases[2] point in the same direction. Rare, dynamic, and highly contingent events do not lend themselves readily to quantification and statistical analysis (Kittel and Kuehn, 2012, :3). In the light of the theorized causal relation (and the admittedly long causal chain), case study methods are more promising to identify and retrace the causal mechanism of interest and to address the complexity of the argument.

[2]Even though Mitchell (2003)'s comprehensive *International Environmental Agreement Database* samples over 1,000 environmental regimes, few of them show the necessary variance on the independent variable and show ultimately no variance on the depend variable since it lists only the results of successful regime formation processes in the form of an international regime.

All these factors make this study to appear as being predetermined for a small-n case study design. On the other hand, a single-case study sacrifices the opportunity to draw more generalized conclusions on factors that influence regime formation. Previous research on the role of scientific knowledge and regime formation has mainly been conducted as single-n case studies of successful regime formation processes (Kydd, 2001; Mitchell and Bernauer, 2004; Morrow, 2001; Oatley, 2001; Pahre, 2001; Richards, 2001; Rosendorff and Milner, 2001; Underdal, 2002; Young, 1993). Though ideographically informative, the explanatory leverage of these studies is limited to tentative conclusions on causal relationships between knowledge and regime formation that leave only small ground for generalization.

The theoretical argument is complex and subtle. Testing it against a single case increases the danger of artifactual conclusion and measurement errors. This study aims at enhancing external validity by comparing a small set of cases that vary on the independent as well as the dependent variable. To draw inference from comparing cases requires controlling for other potentially causal factors. However, the strategy of comparing few cases that vary in cause as well as in outcome while other possible causes are controlled for through the selection of similar cases (most similar systems designs) has been controversial over the last few years (George and Bennett, 2005; King et al., 1994; Landman, 2008; Lieberson, 1991). The strongest critics of MSSDs even suggest abandoning it from the qualitative methodological portfolio (Lieberson, 1994, :1236). Nevertheless, if employed with caution and if inferential conclusions are not overstretched, the design can be usefully employed.

Needles to say that the high requirements for case-selection in perfect MSSDs - variance on the independent variable(s), variance on the dependent variable while all other factors beeing similar - are hardly if ever met in reality and most MSSDs are imperfectly designed. Nevertheless, imperfect MSSDs can be informative in three ways: First of all, they allow to pretest for the hypothesized causal effect. Finding an expected covariation in an imperfect design does arguably not yet allow to draw resilient inference, since not all possible alternative explanations can be controlled for. Nevertheless, it is a first hint whether the hypothesis *might* be supported or dismissed. Secondly, it facilitates the selection of cases for a subsequent within-case analysis where conclusions about causal effects are to be underpinned or dismissed by an investigation of the underlying causal mechanisms through process tracing.

Kittel and Kuehn (2012) have stated in their recent contribution that "[...] despite the outstanding career of the terminology of process tracing, there has been little success in formalizing its methodology and defining standards". The perhaps most commonly agreed definition of process tracing is offered by George and Bennett (2005), who define it as "[...] the attempts to identify the intervening causal process - the causal chain and mechanism - between an independent variable and dependent variable" (George and Bennett, 2005, :206). A more application-centered definition of process tracing is offered by Collier (2011) who defines process tracing as "[...] the systematic examination of diagnostic evidence selected and analyzed in light of research questions and hypotheses posed by the investigator." (Collier, 2011, :1) Diagnostic evidence is often understood as part of a temporal sequence of events or phenomena (Collier, 2011, :3). This study follows Collier (2011)'s understanding of process tracing.

Combining cross-case comparison with in-depth within-case comparison as suggested by contemporary literature on qualitative methodology (Brady, 2010; George and Bennett, 2005; Rohlfing, 2012) promises insights on both the causal effects as well as the underlying causal mechanism. While cross case comparison aims at revealing causal effects among a certain population of cases, underlying causal mechanisms[3] are best examined through within-case analysis (Rohlfing, 2012) .

The considerations of the previous sections lead to a research strategy that aims at selecting four cases that fit the criteria elaborated in section 4.3 and embed the cases into a small-n comparative design[4]. The selection strategy follows the logic of MSSD, though the criteria of perfect similarity are relaxed. This means that the selected cases are still to share a maximum of similar features, but dissimilarities

[3]Causal mechanisms are defined according to Checkle as "[...] a set of hypotheses that could be the explanation for some social phenomenon, the explanation being in terms of interactions between individuals and other individuals and some social aggregate." (Checkel, 2008, :115)

[4]The selected cases are presented in section 4.3.1

do not automatically exclude them from the study. Rather, the selection criteria in section 4.3 ensure comparability.

In a second step, the cases furthermore analyzed through process tracing techniques. This approach promises to diminish some disadvantages of ‘pure’ MSSDs as well as ‘pure’ single-n case studies. It circumvents the precarious control of alternative variables in MSSDs since a close investigation of the causal mechanism reveals a possible impact of other factors. Furthermore, the strategy allows insights on the causal ‘black box’ left by covariational designs (Beach, 2012) and accounts for causal complexity which is omitted by pure MSSDs (Levy, 2008).

The strategy improves causal claims of single-n studies, since it systematically includes variance on the dependent variable. It is therefore more resilient towards selection effects where the causal relationship between an independent variable x is and a dependent variable y is case specific and not systematic. Secondly, it enhances external validity by observing that not only x leads to y in a specific case, but also that non-x led to non-y in a comparable case.

4.3 Universe of Cases, Selection and Cases

The previous considerations on qualitative comparative case studies of the preceding section directly tie in with considerations on the universe of cases, that is the set of cases to which the hypothesis should apply (Geddes, 2003). ‘Cases’ in regime study are typically issue-specific legally binding multilateral agreements. This research, however, purposely includes failed regime formation processes to reflect the whole spectrum of the dependent variable. Therefore, the universe of cases has to include all failed attempts of regime formation. From the point of initiation, regime formation processes can go both ways: they can either end successfully or not successfully. Hence, the universe of cases comprises all initiations of regime formation processes – or, more specifically, all demands for an international regime. Furthermore, research question focuses on regime formation under the condition of scientific uncertainty. This further limits the universe of cases to issues that – at least potentially – involve scientific uncertainty.

Common pitfalls in selecting cases for comparative case studies have been widely discussed (Geddes, 2003). To avoid these pitfalls, King et al. (1994) suggest a variable-guided case selection. The strategy for selecting has to incorporate the justifiable assumption of causal homogeneity (Brady, 2010, :111). Causal homogeneity is defined by King et al. (1994)[5] in its strong form as "[. . .] the assumption that all units with the same value of the explanatory variables have the same expected value of the dependent variable". The weaker form it is defined as "constant effect assumption" (italics omitted), which means that both variables vary in the same way (King et al., 1994, :91-93). As causal homogeneity in its strong form is rather rare, this study regards the weak as sufficient. The theoretical argument hypothesizes that the configuration of scientific knowledge effects the regime formation process. Hence, the configuration of scientific knowledge is conceptualized as the independent variable which can either occur as 'conducive' or 'obstructive', while the regime formation process is conceptualized as the dependent variable which can either occur as 'successful' or 'stalled'.

King et al. (1994)'s variable-guided case-selection however contains a dilemma: On the one hand, cases have to be selected on the basis of variance of both the independent variable and the dependent variable, as well as non-variance of control variables. On the other hand, finding covariance is usually the result of intensive, resource-consuming collection of data and in-depth analysis. This especially holds when the conceptualization of the variables is complex and data-collection is rather difficult. In a sense, cases have to be selected on the basis of information that is usually the outcome of an empirical analysis and are not known prior to a thorough analysis of the cases. This dilemma accompanies comparative case study designs and cannot be resolved completely. However, it can be limited or circumvented by setting proxies as selection criteria that allow to presume the required variance.

[5] King et al. (1994) refer to "unit homogeneity", which can be understood synonymously (Brady, 2010, :111)

These considerations lead to the following list of selection criteria:

Scope Conditions

Among the policy areas where most international regimes can be found (economy, environment, security and human rights), environmental issues are most suitable for testing the hypotheses since scientific uncertainty can be expected most common in this particular policy issue. Therefore, as a first approximation for selecting cases, all cases have to involve a multilateral environmental issue that affects at least three countries and can only be effectively contained collectively since - as elaborated in chapter 2 and chapter 3 - this is the main motive for actors to form a regime. Additionally, in all selected cases an observable political action (such as an official regime demand) that potentially could end in an international regime has to be identifiable.

Variance on the Independent Variable

To determine if the configuration of scientific knowledge is either 'conducive' or 'obstructive' at a certain point in time or changed in either direction over time is a the result of a complex operationalization and interpretation of data and hence cannot be employed at an early stage of the research process. However, a superficial scan of secondary literature is presumed to be sufficient to presume variance on the independent variable. As this study supplements a cross-case comparison with a thorough within-case process-tracing, the latter strategy is expected to reveal if cases show necessary variance on the independent variable. Cases that do not show the necessary variance will be withdrawn from the analysis.

Variance on the Dependent Variable

The challenge of distinguishing a 'regime' from a 'stalled regime' is to be explored in the next section (see 4.4.2). For the purpose of selecting cases, a government document or a document by an international organization that is (a) addressed to at least three governments and (b) explicitly calls for legal regulation of a multilateral issue qualifies as a demand for a regime; the expressed demand for a regimes qualifies for possible inclusion of a case. On the opposite side of the spectrum stands the a legally binding agreement that is signed by all relevant states.

4.3.1 The Cases – A Brief Outline

Among the university of cases, four regime formation processes (cases) match the outlined criteria and have been selected for this study: (a) the regulation on persistent organic pollutants (POPs), (b) the protection of the stratospheric ozone layer, (c) the issue of Arctic haze and (d) the protection of global forests. While the first two cases are regulated by international regimes, the latter two cases have experienced substantial political activity without any transnational commitments. Furthermore, all cases deal with transboundary environmental issues that affect at least three countries and were (or still are) prone to scientific uncertainty[6]. They share a comparable number of involved parties and a rather homogenous composition of involved players since the regime formation processes under investigation were all dominated by western industrial nations, but also included countries with developing economies. Variation in the composition of parties should hence not account for the observable variance of the dependent variable. All regime formation processes were initiated during or before the time span between 1980 - 1987 and ended after 1995. Therefore, all four formation processes started during 'Cold War' times and experienced the 'shift of tides' in world politics. A change of major power constellations should therefore not account for the success or failure of a regime formation process.

The case of stratospheric ozone depletion has been selected as it has repeatedly been studied to investigate the relationship between scientific knowledge and political action by several authors (Dimitrov, 2006; Haas, 1992a; Parson, 2003; Skodvin, 2000). On the other hand, the ozone regime has been used as a case to investigate the impact of rational state interests (Barrett, 2001; Lange and Vogt, 2003). Since the argument of this study integrates both aspects, the case seems to be a perfect

[6]This section provides only a brief overview to underpin the outlined case selection. A thorough investigation on all sketched issues follows in chapter 6

fit for testing the argument. Secondly, the case of stratospheric ozone involves a twisted scientific process that is marked by big turns and shifts in scientific knowledge. Furthermore, it serves as a good example on the non-linearity of a scientific process. This ensures high within-case variance of the independent variable. And last, the case has been under extensive investigation from IR-scholars. Therefore, most pragmatically, data availability is assumed to be very high.

POPs have been regulated internationally since 1998. Their hazardous character is subtle and not easy to trace, which has plagued researchers for decades. The scientific process has therefore been rather difficult and results have been rather tentative. However, states negotiated an agreement emission cuts. The cases is therefore insightful for a regime that was negotiated under rather strong scientific uncertainty.

While the case of stratospheric ozone involves a timely scientific process, the absent regulation of global deforestation is probably the most prominent non-regime in international politics. States have negotiated for decades and did not yet reach an international regime. Additionally, the scientific process is marked by shifts and turns in the understanding of the issue.

The political activity on POPs and on Arctic Haze particularly lend themselves for an in-depth process tracing, since both cases share additional similarities. Both cases fall under the categorization of Sprinz and Helm (1999) as 'global environmental problems', which result from " ... emissions around the globe [which] are aggregated and chemically transformed by an environmental medium (the atmosphere), but the effects of this global mixing vary by region." (Sprinz and Helm, 1999, :362) (italics omitted). Additionally, both issues deal with the as the same geographical region, the Arctic[7]. On the other hand, the political activity on POPs lead to a binding international regime while the activities on Arctic Haze did not lead to such a result. A close investigation promises to trace the causal mechanism that lead to the successful completion in one case and the causal process that lead to the non-completion of the other case.

[7]defined as the region north of 60° latitude

4.3.2 Alternative Explanations

While the selected cases fit the selection criteria and share a high degree of similarity, further alternative explanations need to be considered. Regime theory has identified power, interests and knowledge as possible factors to explain regime formation from a macro perspective (Hasenclever et al., 1996; Rittberger and Mayer, 1993). However, it has been however argued extensively in chapter 3 why interests or knowledge in their pure form cannot explain regime formation under the condition of scientific uncertainty and the central argument of this study addresses both issues in a combination. Nevertheless, it can be argued on theoretical grounds that power explains regime formation under the condition of scientific uncertainty, especially if the profile of scientific knowledge is asymmetrical[8] (Barrett, 2001). By using means of power, an actor with an explicit conducive (or obstructive) profile can transform the expected costs for other states and can therefore push (or hamper) a regime formation (Hasenclever et al., 1996; Kindleberger, 1988). This argument, however, rests on the assumption of a powerful state that has the ability and willingness to coerce other states into forming an international regime. It is mplausible that a single state has had the necessary means of excessive power to do so during the period covered. However, the exercise of softer forms of coercion (often described as a mixture of bribery and arm-twisting (Kindleberger, 1981)) could push states that face an 'intermediate' or 'bystander' profile (see chapter 3) into a distinct direction. This rivaling mechanism deserves special attention at the within-case analysis.

On a micro level, drawing on literature from negotiation studies, scholars have identified leadership as a potential factor to explain regime formation (Breitmeier et al., 2006) that cannot be controlled for through case-selection in this study. Leadership as defined by Young (1991) as "[. . .]actions of individuals or entities who endeavor to solve or circumvent the collective action problems that plague the efforts of parties seeking to reap joint gains in processes of institutional bargaining" has been identified as a possible necessary condition for regime formation by

[8] I refer to Scott Barrett's concept of asymmetry of interests which is explained in detail in chapter 2.1

several empirical studies. Especially in the case of stratospheric ozone protection, U.S. leadership has been proposed as a causal factor for the success of regime formation (Benedick, 1998). This, however, contradicts with other empirical findings where regime formation processes failed despite large U.S. support and leadership (Dimitrov, 2006, :168). Nevertheless, the presence or absence of leadership could account for the variance of regime formation for two reasons: Young (1991) points out that leadership becomes more relevant in situations that are not well specified and where actors are not sure about their payoffs. In these situations, leadership functions as a channel of communication. According to Young (1991), leadership in international negotiations facilitates the process by coordinating positions and identifying and communicating a contract zone. These functions can become even more prominent when actors face scientific uncertainty since a potential contract zone is harder to identify and a regime formation process might therefore stall. Framing issues into negotiable packages through leadership can be considered as a necessary condition for successful regime-formation. Therefore, the role of political leadership deserves special attention within the process tracing.

Variance of administrative and organizational support for a negotiation process can strongly affect the outcome. Depending on funding and capabilities, structural support like preparatory (scientific) reports can either be strong or weak. A routined global IGO as for example UNEP can be expected to host international negotiations and coordinate pre-negotiation information flow. Previous research argues that the auspices under which a regime formation process was initiated influences its course and can therefore influence its success. A variation of the organizational degree of the auspices has to be considered in the within-case analysis.

4.4 Variables, Conceptionalization and Operationalization

The conceptualization employs the approach of Goertz (2006). The variables are derived from the theoretical argument, which argues that the configuration of scientific knowledge (the independent variable) effects the regime formation process (the dependent variable). For an empirical analysis, both variables have to operationalized. However, since the differ in there issue, the operationalization has to be adapted case by case. Therefore, this chapter provides framework for operationalizing the variables case by case.

4.4.1 The Independent Variable: Profiling Scientific Knowledge

Scientific uncertainty has been characterized in section 2.2 by the absence of knowledge about a definite outcome, the availability of knowledge about the set of possible outcomes and the absence of knowledge about the likeliness of a single, definite outcome. Table 4.1 is displayed here once again as a refresher. Knowledge about a set of possible future outcomes distinguishes uncertainty from ignorance on the one extreme of the spectrum and certainty on the other end of the spectrum (see chapter 2). The central argument of this study can be summarized as follows: within the subset of cases where actors face scientific uncertainty about the issue at stake, the configuration of scientific knowledge affects the outcome of a regime formation process by turning actors into ‘pushers’ (conducive profile) or ’draggers’ (obstructive profile). The configuration of scientific knowledge frames the set of possible future outcomes as described in 2.2. This profile comprises two dimensions: (a) the *level* of uncertainty (section 4.4.1.2) and (b) the affected *dimension* (section 4.4.1.1).

	certainty	*risk*	*uncertainty*	*ignorance*
Definite outcome	Known	Unknown	Unknown	Unknown
Probability distribution	'One'	Known	Unknown	Unknown
Set of possible outcomes	Known	Known	Known	Unknown

TABLE 4.1: A Refresher on Uncertainty

4.4.1.1 The Dimensions of Scientific Uncertainty

As this study aims at showing how scientific uncertainty affects the behavior of rational, cost-benefits-evaluating decision makers, it has to be theorized about what decision makers include in their cost-benefit-analysis (CBA) and how it is affected by scientific uncertainty. The basic understanding of costs and benefits has been outlined in section 4.1. Costs are conceptualized as direct costs from abatement for a domestic economy.

Previous research has conceptualized benefits from international environmental regulation either as (expected) 'avoided damage costs' (Helm, 2000) or as (expected) 'reduced vulnerability (Sprinz and Vaahtoranta, 1994). These can occur through lower rates of negative health effects (as, for example, reduced cancer rates as a result of banning the production and consumption of asbestos (LaDou, 2004)) or avoided infrastructural damages (such as damages from climate change through CO_2). To facilitate comparison, one principle of CBA is the conversion of these costs into monetary values (Kolstad, 2000, :69). In this study, the issues of the different cases share some characteristics as to their political relevance. The actual causes of the issues (e.g. substances and compounds) however vary strongly across cases. Therefore, the actual parameters that actors include in a CBA and especially the associated scientific uncertainty have to be operationalized case-by-case. For example, while Enkvist et al. (2007) include over 30 cost-parameters in their estimation of costs for CO_2 abatement (Stern, 2007, :203), very different parameters have to be included in a CFC cost curve. Nevertheless, the required knowledge for setting up a cost curve can be categorized into different types of knowledge. Thrift et al. (2009)'s concept of different knowledge types can be usefully employed as a guideline:

Knowledge Type	*Specification*
Substance	Types, Character and behavior in the biotic and abiotic environment
Sources	Types, mechanisms, locations of emissions
Extent-intensity	Geographical extends, trends and distribution, ecosystem contamination levels
Consequences	Wildlife effects, human health effects
Political Alternatives	Abatement, substitutes, adaptation

Table 4.2: Knowledge Types (Thrift et al., 2009)

Thrift et al. (2009) disaggregates knowledge into different types to theorize about which type of knowledge influences a political process (Thrift et al., 2009, :355). The categorization helps to identify which type of knowledge is relevant for a county's assessment of costs and benefits in general. For example, a country can only determine its costs from international regulation if it has knowledge about the sources of a harmful substance, e.g. which processes are responsible for emission and how much emission occurs within its own legislation. Furthermore, the development of substitutes or costs from adapting to new environmental conditions has to factored in and hence, knowledge about these factors is crucial. Equally, in order to determine how much a country would benefit from international regulation, one has to acknowledge the concentrations of the substance at stake ('extent-intensity') and possible harmful consequences to human health, wildlife or infrastructure. All types of knowledge are theoretically prone to scientific uncertainty. However, the degree to which a knowledge type is uncertain varies for reasons that will be explained in the next section.

4.4.1.2 The Level of Scientific Uncertainty

The level of scientific uncertainty is measured through three indicators: the number of possible and plausible theoretical explanations, the congruence of theoretical predictions with observables and the deviations between results of empirical testing. These indicators follow the description of Groot and Spiekerman (1969) on the process of empirical research. Empirical research is broadly speaking a process of *observation, theory building* and *theory testing*[9].

Observation, according to Groot and Spiekerman (1969), is the process of collecting and organization of empirical facts. *Theory building* describes the process that induces an explanation for the observation on the basis of prior knowledge, plausible assumptions and logical reasoning with the aim of providing an explanation for the observation. From a theory (or explanatory model), different hypotheses and testable predictions can be deducted. *Theory testing* involves testing the hypotheses against new empirical material. This involves laboratory experiments or field measures. A match between theoretical predictions and empirical results supports a theory.

Empirical research is, however, biased towards prior knowledge. Theory building rests on prior theories and assumptions, theory testing rests on prior existing methods or data (Chalmers, 1990). The process of theory building is highly influenced by the body of prior knowledge and research. Depending on the body of prior knowledge and prior research, an observation can lead to divergent theories and alternative explanations. A scarce body of prior knowledge that rests on tentative assumptions leaves room for multiple causal explanations. Regarding newly emerging scientific issues, theories may be derived from contradicting and untested assumptions. The existence of different theories to explain an observation therefore indicates a high degree of scientific uncertainty.

Similar arguments can be made about the process of *theory testing*. If prior knowledge is scarce, there is only little experience on how to test a theory, measurement instruments are underdeveloped or access to data might be limited. Therefore, theory testing 'at the research frontier' can produce a blurry range of results rather

[9]A theory in this context is "[...] a reasoned and precise speculation about the answer to a research question, including a statement about why the proposed answer is correct."(King et al., 1994, :19)

than a single, unambiguous outcome. Additionally, there are several ways to design empirical testing. Choosing a particular research design, choosing research methods and choosing particular measurement instruments can have implications on the result of empirical testing. If scientific uncertainty is high, it is likely that the results from different research designs produce deviant results[10].

The level of scientific uncertainty in the context of this work is regarded as a function of constraints in *theory building* and constraints in *theory testing*. Constraints in *theory building* are assumed to be reflected by the number of competing explanations within a defined period of time. The existence of competing explanatory theories indicates that science cannot (yet) provide an unambiguous explanation for the phenomenon of interest.

Constraints in *theory testing* are assumed to be reflected by (a) the congruence of theoretical predictions with observables and (b) the difference between measurement results (remaining residuals) that can be found in the scientific literature within a defined period of time.

If theoretical predictions are not congruent with the observables – either through the mere lack of empirical testing or through deviations between observables – a theory remains speculative in nature. If empirical testing produces rather a range of observables than precise observables – either through measurement errors or other factors – a theory remains speculative or vague. Proposed statements on causal linkages might be supported qualitatively, but a quantification of a proposed causal link remains absent.

The level of scientific uncertainty is therefore considered to be very low if a single theory is tested against new empirical data and the theoretical predictions match the results from empirical testing. Vice versa, the level of scientific uncertainty is considered to be very high if multiple explanatory theories intend to explain an observation and there is either no empirical testing or empirical testing is not convergent with theoretical predictions. This is also the case if there is a high

[10]For example, even running the same computer models on different computers changes model predictions.

Number of Explanations	*Congruence of Predictions with Observables*	*Deviations between results of theory testing*	*Level of uncertainty*	*Symbol*
Single	yes	low	very low	- -
Single	yes	high	low	-
Single	no	-	medium	%
Multiple	yes	high	high	+
Multiple	no	-	very high	++

TABLE 4.3: Operationalization of the Level of Scientific Uncertainty

deviation between empirical test results, either as a product of a single empirical test or as a product of different empirical tests. The combinations of *constraints in model building* and *constraints in model testing* and their implications for scientific uncertainty are listed in table 4.3. The scheme presented in table 4.3 will be applied during the empirical analysis to categorize the level of scientific uncertainty in different time-spans and across different sub-issues of the cases (see chapter 5). For that reason, the level of scientific uncertainty is shown in table 4.3.

The concept of scientific uncertainty as a function of constraints on *theory building* and *theory testing* serves to develop a coding scheme that is displayed in table 4.4. The development of the coding scheme follows Mayring (2010)'s instructions for qualitative coding.

Variable	**Definition**	**Occurence**	**Coding Rule**	**Example**
Number of Explanations	A scientific explanation is a set of logically connected assumptions and hypotheses that rest on pre-existing knowledge. It reduces and selects aspects of real-world phenomena to arrive at an informed description or explanation for a scientific issue	Single	A single model claims to provide new, relevant insights on a scientific issue. The model has to intend to clarify a scientific issue. It has to conclude with an informed description or explanation for a scientific issue.	Between 1975 and 1980, Rahn et al. (1977)'s model was the only one that seemed to provide a plausible explanation for Arctic Haze.
		Multiple	At least two theories claim to provide new, relevant insights on a scientific issue. At least two have the intend to clarify *the same* scientific issue.	In the 1970s, three theories claimed to identify ozone-depleting substances.
Congruence of Predictions with Observables	The implications of a model were confronted with empirical data to confirm or disconfirm the implications. Empirical testing comprises computer simulations, laboratory tests or field tests. The results concur with the predictions of the tested theory	Yes	A theory counts as empirically tested if its implications were confronted with empirical data through a transparent research process that meets the basic standards of research as formulated by King et al. (1994)	The theory of a catalyzing chlorine-ozone reaction was frequently tested and confirmed through laboratory tests (see: (Parson, 2003))
		No	Either no or poor (meaning violating basic standards of research practice) empirical testing has been conducted (yet).	during the 1970s, the theory on stratospheric ozone depletion could not be tested, since instruments were technically not feasible.
Deviations between results of theory testing	Results are often expressed in numerical values. Deviations between numerical values of results qualify are regarded as indicator for differences between results.	high or low	All results from empirical testing of *the same* specific scientific issue within a defined time span are collected. The highest value and the lowest value either within or between results of empirical testing serve as the upper- and lower bound to determine the difference.	During the 1970s, the estimates of future ozone loss ranged between 6% and 18%

TABLE 4.4: Coding Constraints in Model Building and Model Testing

4.4.2 The Political Process of Regime Formation as the Dependent Variable

Empirical studies indicate that an international regime is the result of an interactive process between actors that can be – and frequently has been (see: Young (1994)) – categorized in different stages (see figure 4.1). This process can either end successfully or it can stall indefinitely. In this study, a regime formation process is labelled as 'successful' if a group of at least three states sign a legally binding treaty that is thematically bound to the negotiated issue and – if ratified and executed – can be expected to have significant regime consequences[11] on the issue at stake.

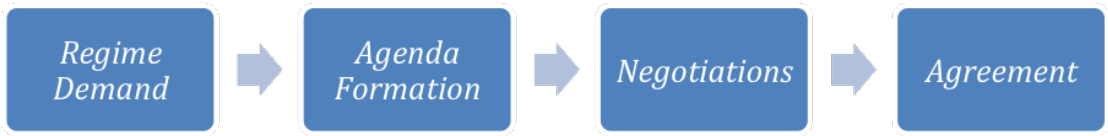


FIGURE 4.1: Regime Formation Process (Young, 1994)

While defining an international regime is rather straightforward, defining a stalled regime is more subtle. For this study, a stalled regime formation process remains at one of the stages displayed in figure 4.1 or even falls back to a previous stage, even though the issue has not been resolved yet. This can happen through three modes: (a) cancelation (b) indefinite suspension or (c) 'drying out' (Janusch, 2012). In the obvious case of cancelation, a country involved expresses its deliberate intention to discontinue the regime-formation process. Similarly, a regime-formation process classifies as suspended indefinitely if countries officially express such a plan. A regime-formation process can be labelled as 'dried out' if no actor takes an initiative to continue the process from one stage to another for a longer period of time. However, one has to be cautious at this point, since the duration of a regime-formation processes can vary significantly. Some robust regimes took decades to build, while others were negotiated within a few years. It is plausible to assume that issues that involve high scientific uncertainty are harder to negotiate

[11] On the topic of regime consequences and regime effectiveness, see: (Hovi et al., 2003; Underdal, 2004; Young, 2001)

and normally consume more time. Moreover, it cannot be predicted whether a negotiation process that stalled for years will eventually be picked up again once the issue becomes prominent again. A regime formation process can therefore only be labelled 'stalled' at a specific point of time or a specific period of time. Young (1989), for example, implicitly attributes 'stalled regimes' to the issue-area of biodiversity and climate change in a publication from 1989 (Young, 1989, :351). While this is true for the time of Young's publication, only five years later two regimes were formed for both issue areas. This example calls for a careful use of the concept 'stalled regime'. A dried out regime-formation process, however, can be defined in dissociation from cancelation: While a cancelled regime formation process stalls with the explicit intend to discontinue negotiations, an indicator for a dried out process is the *absence of declared intention to continue with the process*. This definition is derived inductively from the observation that multilateral negotiation rounds typically close with a declaration of intention by either all or a fraction of the participating states. This declaration usually contains the intent to continue the started process. If such an intent is not declared, the process is likely to dry out.

In conclusion: Both a successful and a stalled regime formation process are initiated by an observable demand for an international regime. While a successful process ends with an official (observable) multilateral treaty, a stalled process is defined by the observable presence of (a) a cancelation, (b) an indefinite suspension or (c) a dry-out.

A third occurrence of the dependent variable has to be considered in regime formation processes. The argument states that if both benefits and costs are uncertain, states engage in coordinating and exchanging scientific information. This can appear in three forms: (a) states form a new international agency, mandated with the collection, review and preparation of scientific knowledge, (b) an existing international agency provides the information or gets mandated to collect, review and process scientific knowledge, or (c) a national research agency collects, reviews and processes scientific knowledge. This will be labeled as a research regime.

4.5 Database and Data Mining

Database and the selection of data vary according to the variables. The scientific process can hardly be retraced on the same database as the political process. Hence, section 4.5.1 introduces the database for retracing the scientific process, whereas section 4.5.2

4.5.1 Data for Retracing the Scientific Process

For retracing the scientific process, peer-reviewed scientific journals serve as primary database. This strategy rests on the assumption that in modern peer-reviewed academia, authors either articulate the blank-spots and uncertainties in their own work themselves or – if a contribution found any recognition – inconsistencies and rivalling hypotheses are proposed by peers and other scholars. Therefore, degree and dimensional impact of the profile of scientific knowledge can be assessed through scientific publications. Within the field of natural science, *Nature* and *Science* are the most recognized scientific journals. Both journals share an over-the-top impact factor and cover the necessary time-span. Publications from both journals on the issue of interest can be reasonably considered as (a) a trustworthy source to evaluate the state of science and (b) can be considered to be highly influential for academia. An analysis of publications from *Nature* and *Science* also allows to discover two additional, more issue-specific journals: Both *Nature* and *Science* are scanned for the most frequently cited journals. The two most highly cited journals will be included in this analysis.

This strategy, however, entails two dangers: First of all, the strategy implicitly assumes that the scientific debate is fully represented in the selected journals. This is a strong assumption, since environmental issues in the selected cases are very diverse and distributed across disciplines. It is possible, for example, that highly influential articles for the assessment of negative health effects are not published in a journal that is specialized on environmental issues, but in a scientific journal that is specialized on specific types of cancer. Since *Nature* and *Science* usually provide overview-articles, an article that contributes a shift in the general scientific understanding could be neglected. Additionally, the selection of journals rests eventually on the 'Journal Impact Factor' (JIF) to evaluate the importance of scientific contributions. The criticisms and limitations of this approach are commonly known (for an overview, see Moed (2005)).

To remedy this danger, an additional computer-aided citation analysis is supplemented. A citation analysis is a tool usually employed in network analysis and bibliometry to identify prominent authors, articles or journals within a scientific field. It usually builds on citations and co-citations and includes forward- and backward- citations, meaning that it includes citing and cited publications. A backward-citation is also referred to as 'reference', a forward citation is called 'citation' (Moed, 2010). This technique enables to cluster publications and relate them to each other. It allows to identify scientific bursts, shifts of paradigms within science and a distinction of a scientific base from a scientific front (Chen, 2006). After the introduction of the comprehensive Scientific Citation Index, scholars used citation data to evaluate the quality of scientific contributions by focusing on the frequency of citations (Garfield, 1979). With the improvement of computer technology, the same dataset was used to develope more complex models of cross-relations between authors. Different software tools are now available to perform this task.

Tracing the history of scientific knowledge in peer-reviewed journals allows one to account for what was recognizably known at different points in time. It allows not only to state how much was known but also how it affected or changed the perception of costs and/or benefits. It has to be noted that the strict peer-review process debars some scholars from publishing in scientific journals and grey literature may contain ground-breaking scientific findings. However, it can be reasonably assumed that political decision makers only consider scientific knowledge that meets high standards of quality. Even if there were ground-breaking scientific findings hidden in grey literature or journals of low impact, it can safly be assumed that these findings would not shape the perception of costs and benefits of political decision makers.

4.5.2 Data for Retracing the Political Process

Official government documents as well as primary and secondary literature serve as the data-source to account for the *dependent variable*. As mentioned in the previous section, cases where a regime formation process dries out are most problematic. It is likely that these cases are not officially documented and secondary literature merely reects the judgement of the author. Elite interviews offer a fall back strategy for cases where a regime formation process is suspected to have dried out. Actors who were or are closely involved in a regime formation process are assumed to offer insights on whether the states involved intend to pick up on the process or are willing to abandon it.

4.6 Summary

The preceding chapter has outlined the 'hows and whys' of the empirical study. In a nutshell, this study employes a comparative cross-cases design of four cases, which is followed by a within-cases process tracing. This allows in a first step to identify covariation across cases and, in a second step, provides the opportunity to search for the actual mechanism which is causing the covariance. The independent variable is operationalized through the degree of scientific uncertainty (which can be either high or low) and its directional impact (which can either lead towards costs or towards benefits). The dependent variable has been operationalized through either a successful regime formation process (which becomes observable through an actual signed multilateral agreement) or a stalled regime formation process (which appears as either canceled, indefinitely suspended or dried out).

The research design is the result of deliberate choices for particular strategies and methodologies. Even after careful considerations of multiple alternatives, most choices involve compromises and can be scrutinized on different levels. While the choice for a qualitative design seems most justifiable in the light of the complexity of the argument and the derived variables, it can be argued that the selected cases are not ideal and better cases might exist. First of all, it can be argued that the cases are not similar enough to employ the logic of a comparative design that aims at maximizing variance of the independent- as well as the dependent variable while minimizing variance on all other potential factors. The cases differ on many factors that could hold explanatory power. For example, neither size nor composition of involved actors are perfectly similar. Even though there is a high degree of congruence, deviations between size and composition might be crucial. Secondly, the cases run on different time-scales. This means that political choices were made under different international and domestic conditions. Foreign policy and the willingness to engage in institutionalized international cooperation might depend on domestic paradigms that shift over time and with legislators (Pierson, 2011). Though cases were selected in a way that they cover big historic tides on the international level (such as the end of the Cold War), influence from convictions and believes of domestic policy makers that shift as domestic policy makers are replaced over time through elections (or similar political changes) cannot be ruled out through the presented research design.

The research design can be criticized also from a more technical and methodological perspective. Not only case selection might bias inference, but also conceptualization, operationalization, data selection and analytical methods could be arguably misleading. One main contribution of this book is the inclusion of non-regime cases into the analysis. However, the whole concept of non-regimes could be considered as an artifact. First of all, there has been a conceptional choice to define non-regimes as cases where political negotiations that aimed at forming a regime did not lead to a regime formation. Alternatively, a non-regime could also be considered as a case where states would benefit from institutionalized cooperation but do not take any action towards this direction. This has implications for the conceptualization of the dependent variable. It can be reasonably argued that states only engage in a regime-formation process or express a demand for a regime if they see a chance that their demand could lead to an international regime *at all*. Therefore, considering only cases in which political action has already been taken in some form biases research towards positive cases in which there is no non-regime, but merely a 'not yet'-regime, especially when negotiations were not deliberately aborted, but experienced a continuing halt. This ties in with a second caveat. The previous chapters have justified the case selection and the choice for the environmental sector with the scarcity of non-regime cases. However, if a non-regime is defined as it has been in this study, the opposite might be true: there are plenty (almost too many) non-regimes, depending on the time-frame under consideration. Literally every international regime started with a regime demand which was followed by negotiations and a regime formation process. Therefore, literally every international regime started as a non-regime case. Even though this caveat has to be acknowledged, it is not as problematic as it seems at first glance. Whether a regime is a 'true' non-regime or simply a 'not yet'-regime has only little effects for testing the theoretical argument. On the contrary, observing when and how a 'not-yet' regime turns into an international regime offers an opportunity to furthermore test the argument. If scientific knowledge and political action are interrelated, a change in political action should be observable only after a change in scientific knowledge became clear.

The alternative definition of non-regimes – policy issues that theoretically could be managed "better" through international regimes – has implications for the research progress that seemed to be even more controversial. Defining a non-regime in such a matter implies that what state actors regard as more beneficial is objectively accessible. This, on the one hand, implies that it is possible to objectively asses what actors consider as beneficial for themselves. On the other hand, such a definition of a non-regime might reflect the concept better, but it is a lot more difficult to trace empirically. If there has not been any political action towards regime formation, what could be empirical data through which the argument could be tested? How could 'political inaction despite potential gains from cooperation' be operationalized? Since these questions remain unanswered, this study took the deliberate choice for the specific definition of a non-regime.

Concerning the operationalization of the the independent variable, transferring aspects of knowledge into knowledge about costs or benefits might seem an abstraction that rests on strong assumptions on how actors perceive and progress information. This transfer is, however, induced by the theoretical argument. The argument assumes that scientific knowledge effects actors' perception of either costs or benefits.

Chapter 5

Empirical Analysis

This chapter provides the empirical analysis of four cases – Persistent Organic Pollution, Stratospheric Ozone protection, Arctic haze and Deforestation. Each chapter begins with a process-tracing analysis of the progression of scientific knowledge. This is followed by a process-tracing analysis of the political process. In a third step, data on costs and benefits is analyzed.

5.1 International Regulation of Persistent Organic Pollutants (POPs)

Despite the high degree of scientific uncertainty, countries implemented strong multilateral regulation on POPs through two multilateral agreements. Given the success of the regime formation process (the dependent variable), the theoretical argument leads to the expectancy that the profile of scientific knowledge has been conducive, meaning that by the time the agreement was struck costs appeared to be low while benefits were uncertain. Additionally, section 5.1.3 will show how highly uncertain scientific knowledge was after early concerns on POPs were raised. This leads to the expectation that the first political activities on an international level were science-oriented and calls for coordinating scientific efforts. The theoretical argument would also lead to the expectation that states were rather similar in their cost-benefit-configuration, or that dissimilarities were compensated in some form.

POPs are man-made chemical compounds of organic[1] nature with toxic characteristics. They are persistent, prone to long-range transport and were extensively used as fungicides or pesticides in the agricultural sector (such as DDT), as flame retardant or diluent (for example PCB) by the electronic industry or simply were unintended by-products of industrial processes. The mix of chemical substances which is grouped under the label 'Persitent Organic Pollutants' is heterogenous and the substances vary significantly in their distribution, severity and harmfulness (see table 5.1). While some POPs are acutely toxic and cause immediate and severe human health problems, others endanger only marine fish and mammals after long-time chronic exposure (Ritter et al., 1995). With some exceptions, the substances are suspected or proven to be carcinogen (IARC, 2013). Additionally, some are suspected to disturb the hormonal balance (so called 'endocrine disruption') and the immune system (Bertazzi et al., 1998). They share similarities in their chemical composition, their half-life in fatty tissue, their tendency for bioaccumulation, and their long-range transboundary migration patterns. Especially the latter sparked multilateral action as residues of POPs were detected in remote areas such as the Arctic or Antarctica. For a comprehensive overview on the usage of POPs and possible negative effects, see table 5.1. With regards to the negative health effects, it has to be noted though that some findings rest on a rather fragile evidential base (see annotations in table 5.1) (Longnecker et al., 1997).

Concerns about possible undesirable effects on wildlife and human health led to international political action which resulted in two multilateral environmental agreements: the 1998 Protocol on POPs under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) and the UN Convention on POPs (Stockholm Convention) in 2001. The LRTAP Convention serves as an umbrella treaty system with specific protocols and was established in 1979. It is signed and ratified by 51 countries, including Canada, USA, Russia and all European countries (Sprinz and

[1]POPs are "Organic" since their molecular structure is based on carbon.

Substance	*Use*	*Health Effects*
Aldrin	Pesticide	Depresses reproduction, suppresses immune System, increases liver cancer
Chlordane	Pesticide	Depresses reproduction, suppresses immune system, tumor promoter
DDT	Pesticide	Egg-shell thinning, depresses reproduction, suppresses immune system, adrenal cortex hyperplasia (cell-mutation in kidney)
Dieldrin	Pesticide	Depresses reproduction, suppresses immune system, increases liver cancer
Endrin	Pesticide	Acutely neurotoxic, affects enzyme system
Heptachlor	Unintended by-product	Depresses reproduction, estrogenic modulation, suppresses immune system, non-mutagenic tumor promoter
HCB	Pesticide	Depresses reproduction, foetotoxic, suppresses immune system, increased porphyria (malfunction of the enzyme system)
Mirex	Pesticide	Depresses reproduction, suppresses immune system
PCB	Industrial chemicals	Depresses reproduction, foetotoxic, decreased memory and dopamine, suppresses immune system, non-mutagenic tumor promoter, increased porphyria (malfunction of the enzyme system)
PCDD (Dioxin)	Unintended by-product	Depresses reproduction, foetotoxic, deformities, decreased memory, non-mutagenic tumor promoter, increased porphyria (malfunction of the enzyme system)
PCDF (Furans)	Unintended by-product	Depresses reproduction, foetotoxic, deformities, decreased memory, non-mutagenic tumor promoter, increased porphyria (malfunction of the enzyme system)
Toxaphen	Pesticide	Depresses reproduction, foetotoxic, suppresses immune system, non-mutagenic tumor promoter, bone brittleness in fish

TABLE 5.1: Possible Health Effects and Usage of POPs (Longnecker et al., 1997)

Vaahtoranta, 1994)[2]. The Protocol on POPs was signed by 33 LRTAP-parties in 1998 after ten years of assessing the scientific knowledge and negotiating an agreement. The assessment process resulted in the first conclusive assessment reports on POPs (Eckley-Selin, 2006, :178).

The Stockholm Convention on Persistent Organic Pollutants, on the other hand, was signed by 92 states in 2001 and became effective in 2004 after the ratification of the fiftieth signatory state. It was negotiated over three years between 1998 and 2001 under the auspices of the United Nations Environmental Program (UNEP) and regulates or restricts the production, use and trade of POPs. The negotiation process was preceded by scientific assessment of the International Forum for Chemical Safety (IFCS) which conducted an assessment report on toxicology and transport of POPs (Ritter L., 1998). The Stockholm Convention has a broad membership (by 2013, 172 countries had ratified the document)[3].

Scholars and participants of POPs negotiations alike agree that the scientific assessment for the Stockholm Convention heavily relied on the preceding scientific work that had been conducted for the CLRTAP Protocol on POPs (Eckley-Selin, 2006). For example, the scientific assessment conducted for the Stockholm convention repeatedly refers to the CLRTAP Protocol's scientific assessment (see Ritter L. (1998)).

Since the scientific assessment as well as the political process of the CLRTAP protocol preceded the Stockholm Convention, the CLRTAP Protocol is more lucrative for the study of both processes. Therefore, this study will exclusively focus on the LRTAP protocol.

[2] For a complete list of members, see: `http://www.unece.org/env/lrtap/status/lrtap-st.html` (21.10.2013)

[3] for a complete list of signatory states, see: `http://chm.pops.int/Countries/StatusofRatifications/tabid/252/Default.aspx` (22.10.2013)

5.1.1 Defining Costs, Benefits and Uncertainties of POPs

The study aims at retracing the development of scientific knowledge on POPs and the linkages to political action. The argument in chapter 3 states that with regards to political action on the international level, the configuration of scientific kowledge can either be conducive or obstructive. Secondly, it states that new scientific knowledge can reshape the configuration of scientific uncertainty (e.g. from obstructive to conducive and vice versa). Since the issue of POPs was already found to be characterized by scientific uncertainty at the previous step of case selection (see section 4.3) and POPs are regulated internationally, we would expect a conducive profile. Linking the case-study to the theoretical argument (see chapter 3) requires a clear-cut definition of costs and benefits in the case of POPs.

Costs resulting from the regulation POPs are conceptualized in line with Sprinz and Vaahtoranta (1994) as pure economic costs from regulation. As an operationalization of economic costs has to capture the economic value or significance of POPs, they are operationalized as the absolute production, use[4] and waste disposal of POPs, which are best captured by emission data (Pacyna et al., 2003). The operationalization follows the logic that the higher a country's emissions, the higher the costs from international regulation (Sprinz and Vaahtoranta, 1994, :88).

Benefits from regulating POPs are conceptualized (again in line with Sprinz and Vaahtoranta (1994)) as reduced vulnerability. In the case of POPs, vulnerability is determined by the possible hazards from POPs and the exposure to POPs. Intuitively, it can be assumed that states regard their vulnerability towards POPs as high if they regard POPs to be hazardous, since this is the reason to expect harmful consequences. On the other hand, vulnerability can only be high if a country faces actual *exposure* to a hazardous substance. This follows the presumption that a country is primarily concerned with its own well-fare and merely pays lip service to concerns about "Mother Earth" in general. If a country's territory is not

[4]'use' includes export of POPs

affected by a harmful substance, it can be presumed that it expects no harmful consequences.

Therefore, if exposure-rates are high *and* compounds lead to negative effects, benefits from international regulation are high and vice versa. The conceptualization of benefits is therefore a conjunction of hazardousness and exposure, which can be expressed as *vulnerability = hazardous nature of POPs * exposure*. If both are high, benefits from international regulation are high. If one or both indicators are low, benefits from international regulation are low.

Concerning changing knowledge we would expect that initiatives for international action followed a conjunction of findings on negative effects caused by POPs and findings on their transboundary movement. If POPs were only hazardous and not prone to transboundary movement, pure national legislation would be sufficient to address the issue. If they were only prone to transboundary movement but rather harmless, there would no reason to tackle the issue on an international level. Only the conjunction of both would be a reason to regulate them internationally. The subsequent case study intends to reveal whether this was the case or whether other factors provide a more robust explanation for the emergence of the POPs regimes.

5.1.2 The Outline of the Case Study

To determine how scientific knowledge was shaped and how it changed over time, the scientific literature on the issue of POPs is analyzed. Two methods are employed to select the most relative contributions from the vast body of scientific literature: First, contributions are picked from highly influential journals *Nature, Science* and two additional journals that are prominent in the field of interest. This step aims at identifying the dominant research themes during different time spans. Secondly, the vast body of scientific literature is analyzed through a citation analysis using ‘CiteSpace’. This second step ensures that highly influential publications which were not published in one of the selected journals, but were frequently cited by other contributions and can therefore count as highly influential are also included into the analysis. The results of the citation analysis serves as a basis for the qualitative content analysis.

5.1.2.1 Scanning Highly Influential Scientific Journals

As a first step, *Nature* and *Science* are screened for publications on POPs. Furthermore, the journals *Science of the Total Environment* and *Atmospheric Chemistry* have been identified as highly relevant to the issue through a review of the references within the articles of *Science* and *Nature*. All four journals offer an accessable historic database and were scanned for the period between the years 1948 (the beginning of the commercial introduction of organochlorine pesticides) and 2001 (the year of the Stockholm convention) for the keywords 'DDT', 'Aldrin', 'Chlordane', 'Dieldrin', 'Endrin', 'Heptachlor', 'HCBs', 'Hexachlorbenzene', 'Mirex', 'PCBs', 'Polychlorinated Biphenyls', 'Furans', 'Dioxin', 'Toxaphene', 'Persistent Organic Pollutants', 'Organochlorine Pesticides'. The search resulted in 438 articles that cover the issue. A systematic overview of the results is made available in appendix 7. The results of the first step of data collection was used to identify dominant research topics (see table 5.2). This is relevant to determine different dimensions of scientific uncertainty.

As a result, the scientific themes 'Resistance', 'Persistence', 'Uptake and Storage', 'Effectiveness', 'Negative Wildlife Effects', 'Negative Effects Human Health Effects' and 'Transport' were identified. An overview with specifications is provided in table 5.2.

Data collection and analysis of the articles in *Science, Nature, Science of the Total Environment* and *Atmospheric Chemistry* show that different scienitfic issues dominated research through different periods in time. In the early years (between 1948 and 1975), researchers were mainly occupied with (a) mechanisms that cause resistance of targeted insects (such as locust, cockroaches or mosquitos), (b) the persistence of pesticides in soils and water and (c) the effectiveness of the pesticides. Within the scientific process, research on PCBs began later. During

Theme	Specification
Resistance	The degree and underlying mechanism on how different insects develop resistance towards insecticides
Persistence	The half-life of POPs in soils, water, air and tissue. Mechanisms of biodegration.
Uptake and Storage	POPs in different food-chains. Metabolism and storage of POPs in animals and humans.
Effectiveness	The acute effects of POPs (toxicity and micro mechanism).
Negative Wildlife Effects	Adverse effects from sub-leathal, small dosed, long-time exposure for animals.
Negative Human Health Effects	Adverse effects from sub-leathal, small dosed, long-time exposure for humans.
Transport	Different mechanisms of how POPs migrate over distances.

Table 5.2: Themes of POPs in Scientific Journals

the early 1950s, nearly all research effort on POPs was directed at improving the effectiveness of pesticides by avoiding resistance, enhancing persistence and understanding the micro-mechanisms of lethality. Themes like negative wildlife effects, negative health effects and uptake and storage were only addressed by a few publications which mainly dealt with negative effects from acute toxicity. The themes 'negative wildlife effects', 'negative health effects' and 'uptake and storage' became prominent in the mid 1960s and clearly dominated in the 1970s, also sparked by events as the Seveso dioxin spillage. During this period, the first negative effects from sub-leathal, small-dosed chronic exposure (like reproductive failure of birds and fish) were investigated. The search for alternatives entered the scientific debate between 1975 and 1985. The scientific debate on transport and migration of POPs had been going on since the late 1960s, but major uncertainties had not been resolved until the early 1990s.

5.1.2.2 Citation Analysis

The underlying rationale and a detailed description of citation analysis are elaborated in chapter 4. This section will therefore focus on the case-specific implementation of both methods. The method aims at filtering the most relevant information that was present at different points in time within the scientific debate. The results are crosschecked with the official assessment reports.

The citation analysis using 'CiteSpace' uses the dataset of the 'Scientific Citation Index' and identifies citation networks by connecting scientific papers according to the backward citations and forward citations[5]. In a first step, a data-set was generated by searching the keywords 'DDT', 'Aldrin', 'Chlordane', 'Dieldrin', 'Endrin', 'Heptachlor', 'HCBs', 'Hexachlorbenzene', 'Mirex', 'PCBs', 'Polychlorinated Biphenyls', 'Furans', 'Dioxin', 'Toxaphene', 'Persistent Organic Pollutants', and 'Organochlorine Pesticides' within the Scientific Citation Index. In a second step, the gathered citations were analyzed through 'CiteSpace' and allocated to the above mentioned research themes. CiteSpace uses citation data to identify citation networks and citation pathways through the historic development of science. It allows to identify landmark articles and scientific bursts. This resulted in the identification of 53 highly important publications for the issue of POPs. A overview on the publications in emphNature and *Science* is made available in the appendix.

The citation analysis leads to a manageable amount of scientific literature allows to conduct a qualitative content analysis (Mayring, 2010). The literature analysis further includes the official assessment work which has been conducted by the LRTAP working group on technology with support of the International Programme on Chemical Safety (IPCS). The efforts of both agencies resulted in two comprehensive assessment reports, the "State of Knowledge Report of the UN ECE Task Force on Persistent Organic Pollutants" (UN.ECE, 1994a,b) and the IPCS report

[5] 'backward citation' means a citation within the paper in focus, 'forward citation' describes a citation of the paper in focus.

"A Review of Selected Persistent Organic Pollutants" (Ritter et al., 1995). Expert interviews ensure that the following account on the development of scientific knowledge on POPs is as conclusive as possible.

The historic steps of scientific advancement, as well as paralleling political action are roughly divided into decades. Data on the political action was obtained from the official documents, provided by the UN ECE and secondary literature (Eckley-Selin, 2006; Selin, 2000; Selin and Eckley, 2003).

5.1.3 Scientific Knowledge and Political Action on POPs from a Historical Perspective

Table 5.1 shows the diversity of POPs both in function and in negative effects. But despite all dissimilarities, POPs share the features that they are (a) resistant towards photolytic, chemical, and biological degradation; (b) they are lipophilic and therefore bioaccumulate in fatty tissue of top predators mainly through the food chain and (c) they migrate over long distances around the globe predominantly through two mechanisms: 'global distillation', a process through which vaporized chemicals travel through atmospheric winds into colder regions and condensate and the 'grasshopper' or 'cold trap effect' where chemicals travel in tune with seasonal temperature shifts[6] (Wania and Mackay, 1993, 1996).

Research on POPs has always been, and still is, in parts fraud by analytical limitations to the extend that experts refer to it as "hitting a moving target" (Shifrin and Toole, 1998). To fully capture the scientific process on the issue of POPs, each of the 12 compounds would need to be investigated individually. The next sections will however explicitly focus on DDT and PCB for several reasons. First of all, both substances appear most prominent in the scientific debate[7]. They represent both the groups of organochlorine chemicals: Pesticides (DDT) and industrial chemicals (PCBs). Second, DDT and PCB are the most significant substances economically. Production, usage and trade exceed the all other POPs

[6] Other mechanisms have also been identified, see 5.3.3.2.

[7] Dioxin appears in a comparable number, this is however caused by the Seveso accident.

by far (Lohmann et al., 2007). Thirdly, the two substances appeared to be the most controversial politically (Selin, 2000). They drew the highest media-attention on a national level and were discussed the most controversially during international negotiations. Therefore, it can be assumed that these two substances best reflect the relationship between scientific knowledge and political action on POPs.

5.1.3.1 Sources and Emissions

In search of an efficient pesticide that was harmless to humans and plants, the Swiss company Geigy developed DDT in 1939. It was widely used during World War II for vector control to curtail typhus, malaria and other deceases. After World War II, the agricultural use of different organochlorine pesticides intensified. They have proven to be an effective and cost-efficient pesticide for a wide range of pests (Wharton and Reid, 1950) and between 1950 and 1980, over 40,000 tons of DDT were used each year (Li and Macdonald, 2005). The extensive use led to pest resistance and, as a consequence, large-scale outdoor application declined during the 1990s. There is only minor use of DDT and other organochlorine pesticides today (Longnecker et al., 1997).

In the early days of its application (1940s-1950s), estimating the sources, emissions and residues in wildlife and humans of DDT remained a difficult task due to methodological limitations. In the 1950s, some findings indicated large residues of DDT and other organochlorine pesticides in soils, and small quantities were found in plants and animal tissue (Edwards, 1966; Edwards and Adams, 1970; Lichtenstein, 1957; MacPhee et al., 1960, :8). Further attention on residues was sparked by Carson (1962)'s famous book 'Silent Spring' and numerous researchers launched projects to trace the amount of residues of organochlorine pesticides in soils, water and the air (Berry, 1967; Brady, 1967; Johnson, 1968; Moore, 1967; Moore and Tatton, 1965; Rudd, 1964). These efforts improved the understanding about persistent stocks of organochlorine pesticides in the physical and biological environment. However, it was not until the early 1970s that organochlorine compounds could be analytically separated and measured (Shifrin and Toole, 1998,

:247). Research techniques sharply advanced as new gas spectrometric procedures (Edwards and Adams, 1970, :8) became available, but many details were still unknown. For example, it remained unclear if pesticides were picked up directly from the air or washed out from circulating dust (Wheatley and Hardman, 1965), which was highly relevant for research on migration patterns. These analytical gaps were not filled until the late 1980s.

PCBs, on the other hand, were industrially produced from 1930 to 1989. They substituted mineral oils that had previously been used for cooling and insolation purpose (Kimbrough, 1989). Manufacturing peaked in the 1960s (Breivik et al., 2004) and by 1972, they were produced in (West) Germany, France, Great Britain, Italy, Japan, Spain, the USSR and the USA (Fiedler, 1997). Unlike DDT and other chlorinated compounds, PCBs were detected rather late since they (a) analytically overlap with other chlorinated pesticides and industrial compounds and (b) their acute toxicity was not a reason for great concern (Shifrin and Toole, 1998, :247). This changed with an accidental high-dosage exposure in Japan that occurred in the late 1960s (see section 5.1.3.2). Systematic research on sources, emissions and residues of PCBs was sparked by a study of Jensen (1966), who's study suggested that PCBs were probably distributed widely around the globe. However, even though measurements and instruments on the quantification of PCBs concentrations improved significantly in the late 1970s and early 1980s (Shifrin and Toole, 1998, :249), the complex nature of PCBs still caused considerable difficulties to researchers when it came to estimating PCBs concentrations during that time period. 209 different commercially produced PCBs existed and unlike other organochlorine compounds, they were not directly released or emitted into the environment. Rather, they were used in condensers and other electronic equipment, making it impossible to track all possible sources. Secondly, considerable amounts of PCBs were produced in unregistered and illegal production sites (Breivik et al., 2004).

In conclusion, the *mechanisms* of emissions of DDT and PCBs were quite well understood when negotiations on the CLRTAP Protocol started. While DDT was deliberately dispersed in the environment through agricultural use, PCBs emissions appeared rather collateral through using and abandoning products containing PCBs. However, very little accurate data existed on *actual emissions and inventories* during the time when the CLRTAP Protocol was negotiated. This is also expressed by the official assessment work of the IPCS and the UN.ECE working group on technology (Ritter et al., 1995; UN.ECE, 1994a). States had therefore only rough estimates on their own emissions that were not transparent to other states.

5.1.3.2 Negative Effects on Wildlife and Human Health

In the early days of application, the abiotic and biotic character of DDT and other organochlorine pesticides was at least partly understood (Thrift et al., 2009) and acute toxicity resulting from organochlorine exposure – such as chloracne (Meigs et al., 1954) – was already known from the beginning of it's usage. The only concerns about the large-scale use of organochlorine pesticides were raised in the early 1950s when scholars discovered an increase of insect population despite the application of pesticides. In 1945, a review of animal studies in the British Medical Journal concluded that there is no reason to anticipate any danger in man from widespread low-level exposure of pesticides (Beard, 2006; Cameron and Burgess, 1945). These findings were supported by small-scoped human trials where no signs of adverse effects after a chronic mild exposure to pesticides were found on test persons (Hayes et al., 1956). Hence, the first warnings did merely suggest improvements in the application of pesticides to avoid ineffectiveness.

This changed with more and more findings about negative effects of DDT and other organochlorine pesticides in wildlife. In the early 1960s, studies reported findings of dead birds and fish close to sprayed fields and woodlands (Robbins et al., 1951; Turtle et al., 1963), but these findings were accepted as unavoidable side-damage (Edwards and Adams, 1970, :8). Even though scholars in the 1950s discovered a rapid decline of certain bird populations in Great Briteain and the U.S. through the thinning of eggshells (Ratcliffe, 1958), this phenomenon was only tentatively linked to pesticides. A linkage between organochlorine pesticides, a change in the endocrine system of birds, egg-shell thinning and a decline in population of certain bird species was first articulated between 1967 and 1968, when two influential publications in *Science* and *Nature* presented laboratory findings (Hickey and Anderson, 1968; Ratcliffe, 1967). This was the first empirical evidence of adverse effects of organochlorine pesticides from chronic, sub-lethal doses for wildlife and was later confirmed by other lab experiments (Peakall, 1969). Two properties of organochlorine pesticides allowed to draw this causal link: Since these substances are highly persistent, they bioaccumulated (Doane, 1962; Edwards, 1965; Keith, 1966) and, in the longer run, change hormonal processes that are responsible for the egg-shell production (Egan et al., 1965; Turtle et al., 1963). These were the first indications of adverse effects of organochlorine pesticides for the environment.

Within that decade, evidence of organochlorine pesticides residues in food and human tissue grew stronger (Egan et al., 1965; Hayes et al., 1963; Robinson and McGill, 1966). However, the British Advisory Committee on Poisonous Substances stated in an official report in 1964 that there was no evidence that the concentration of pesticides found in human tissue do any harm. Only the wide diffusion of these compounds were reason for some concern, but serious adverse effects for humans were not articulated (Advisory Committee on Poisonous Substances used in Agriculture and Food Storage, 1964). An assessment report by the World Health Organization (WHO) in 1979 documented the well-established consequences of acute, high-dosed exposure for humans, but at the same time stated that "in the light of currently available information, there is no evidence that DDT is carcinogenic in man" (WHO, 1979). However, some studies suggested a carcinogenic effects and liver malfunction.

During the 1980s, research indicated more and more different adverse effects for human health, especially different sorts of cancer and reproductive effects (Fry et al., 1981). Studies showed correlations between residue levels and breast cancer (Eriksson et al., 1981; Unge et al., 1984; Wassermann et al., 1976). However, the conclusions from theses studies were limited by methodological mistakes (Longnecker et al., 1997, :219). The links between other forms of cancer such as lymphoma, pancreatic cancer, brain cancer, liver cancer and diabetis seemed even stronger (Alavanja et al., 2003; Blair et al., 1992; Ditraglia et al., 1981; Littorin et al., 1993; Longnecker et al., 1997; Woods et al., 1987). Nevertheless, as Beard (2006) points out, the conclusions from these studies have to be read with caution due to the mentioned limitations. In the light of theses findings and in the light of stronger evidence of negative effects, nearly all signatory states of the POPs-Protocol had installed restricting domestic laws on use, production and trade of DDT by the late 1980s that exceeded the restrictions of previous legislation (see table 7.1).

While knowledge on negative effects of organochlorine pesticides on human health was merely tentative in the 1980s, much research effort had been spent on supporting or dismissing the speculative findings in the decades that followed. The potential carcinogenicity with respect to breast cancer remained unclear with some studies confirming the link (Wolff et al., 1993) and some studies dismissing it (Krieger et al., 1994). Speculations on a relationship between exposure to organochlorine pesticides and pancreatic cancer were supported by cohort studies (Garabrant et al., 1992). Additionally, the suspected relationship between organochlorine pesticides and lymphoma was supported (Cantor et al., 1992). A conclusive and highly cited review-study in a high impact journal from 1997 concludes that besides the long known acute toxicity of high dosed organochlorine pesticide exposure, human health effects were not yet well established. The same study called for further investigation on breast cancer, lymphoma and pancreatic cancer, as well as androgen activity with regard to exposure and residues of organochlorine pesticides.

Cancer did not remain the only reason for concern. Since the role of organochlorine pesticides in reproductive processes in birds had been studied intensively, scholars investigated these effects in humans and came to reasonable assumptions that pesticide concentrations could be linked to miscarriage (Leoni et al., 1989; Saxena et al., 1980), spontaneous abortion (O'Leary and Davies, 1970) as well as prematurity (Procinoy, 1981; Saxena et al., 1980) and other fetus related issues (Rogan et al., 1986a,b). Organochlorine pesticides also were suspected to influence male fertility (Bush et al., 1986), but studies only found scattered evidence. All in all, studies on negative effects of DDT-exposure on reproduction processes remain still puzzling. While some studies conclude strong effects (Longnecker et al., 2001), other studies do not find evidence for a possible causal link (Siddiqui et al., 2003). Early studies showed clear methodological limitations (Beard, 2006, :81), recent reviews showed no statistically significant results (Dalvie et al., 2004).

Possible negative effects from PCBs-exposure entered the scientific debate rather late, since - in contrast to organochlorine pesticides - there was initially no reason to suspect any toxic effects from PCBs-exposure. An accidental PCBs-poisoning in Japan, which caused several casualties in 1969, sparked research on PCBs-effects with an exclusive focus on acute toxicity from highly dosed exposure. These ranged from skin anomalies, deformed nails and teeth to delayed cognitive development in children (Gladen et al., 1988; Ritter et al., 1995).

Negative effects from chronic, low level exposure entered the debate as a spill-over from research on negative effects of organochlorine pesticides in the 1970s (Hammond, 1972; Mosser et al., 1972). Jensen (1966) discovered how wide-spread PCBs were to be found in the environment and, since their chemical composition showed similarities to organochlorine pesticides, researching possible effects of PCBs seemed obvious. Since DDT was already suspected to be carcinogenic, early research focused on this mechanism (Allen and Norback, 1973; Bahn et al., 1976; Blum, 1977; Kimbrough et al., 1975). However, the same measurement difficulties that plagued research on sources and emissions also hampered research on negative effects (Shifrin and Toole, 1998) and data was insufficiently robust to draw a direct causal link (Nelson, 1972).

In the 1980s, research on PCBs and cancer expanded to cohort studies on occupational exposure (Baker et al., 1980; Bertazzi et al., 1987; Brown, 1987; Cammarano et al., 1984; Gustavsson et al., 1986; Nicholson et al., 1987; Woods et al., 1987). The studies were based, however, only on a limited numbers of participants.

Therefore, even though many studies suggested a potential link between PCBs exposure and various forms of cancer, the data remained insufficient. In 1987, the International Agency for the Research on Cancer (IARC) reported that PCBs had been found carcinogenic in animal trial, but not in humans and therefore classified PCBs as "possibly carcinogenic to humans" (Group 2b) (IARC, 1987).

The focused research on negative effects of PCBs led researchers to suggest additional hazards form PCBs to wildlife and human health, such as prenatal neurodevelopment, fetus malformations, miscarriage and immune system suppression (Dar et al., 1992; Gladen et al., 1988; Leoni et al., 1989; Mendola et al., 1995; Rogan et al., 1986a,b; Taylor et al., 1989). Research supported the hypothesis of an influence of PCBs on several hormonal and endocrine processes, but could not identify an unambiguous mechanism, significant correlation or effect (Brouwer et al., 1999). Even though many details were still missing, evidence was alarming enough for many countries to pass national legislation between the 1970s and late 1980s (see table 7.2 in the appendix). In contrast to DDT though, scientific findings on negative effects of PCBs became more robust *after* many countries had passed restricting regulation.

Though over the decades knowledge on negative effects of DDT and PCBs expanded enormously in quantity and quality, the interactions in wildlife and humans of both compounds are highly complex and sensitive to only slight changes in species, age, sex and exposure. There is little doubt about the effects of acute high-dose exposure.

5.1.3.3 Transport and Migration Patterns

The issue of transport paths of POPs was raised in the 1960s after findings of residues in remote areas such as the Antarctic and the Arctic. Finding DDT and PCB in remote areas far from their production sites and deployment sites seemed puzzling (Tatton and Ruzicka, 1967), and scholars began to speculate on transport pathways of organochlorine pesticides. The standard model at this stage suggested that organochlorine pesticides enter the food chain and travel through migrating species such as fish and birds. Alternatively, it was assumed that the substances are diffused into the water cycle and are transported via sea-currents. Both of the models were however contested by residue findings in air samples and water samples at levels that exceeded the amount that could be transported through the food chain or water currents (Abbott et al., 1965).

During that time period, results from a large-scale monitoring project in the Arctic supported previous speculation about the long-range *atmospheric* compounds (Tanabe et al., 1983). A highly cited article from 1989 investigated new data samples and concludes that "...organic compounds, which cannot be explained by the presence of local sources, are occuring in Canadian Arctic snow at measurable concentrations. The only reasonable source for these compounds is long-range atmospheric transport." (Gregor and Gummer, 1989). While long-range atmospheric transport had been documented with certainty for decades for substances such as dust, metal particles or carbon, the overall data on organochlorine pesticides was still inconclusive (Barrie et al., 1992, :64). More insights on long-range transport of organochlorine pesticide were gained by the studies of Wania and Mackay (1993, 1996) who developed the first models of 'cold condensation', a process where substances evaporate in warm seasons into the air and settle back to soil in cold seasons or regions. The hypothesized model was confirmed by several studies (Ockenden et al., 1998) and evidence for its reliability was accumulated (Jones and De Voogt, 1999). These findings were picked up by Rodan et al. (1999) who prepared an early screening report on the mechanisms in collaboration with the U.S. Environmental Protection Agency (U.S. EPA). The report highlights the remaining scientific uncertainties concerning half-life and transport paths. Only a year later, Macdonald et al. (2000) published the results of the five year research project under the Canadian Northern Contaminants Program (NCP), which not only confirmed the existing transport models, but also identified additional mechanisms of atmospheric transport.

5.1.3.4 Summary: Certain and Uncertain Knowledge on POPs

The main finding from the first step of literature analysis is that over time the scientific community has been occupied with different aspects of POPs. These research themes have been sparked by either (a) new puzzling findings (such as residues in remote areas or the decline of bird populations) or (b) by transferring previous scientific knowledge to new aspects that were suspected to be related (such as hormonal effects of DDT in birds to hormonal effects of PCBs in humans).

The main finding of the qualitative content analysis of literature is that research on POPs has been, and still is, a difficult task and that only a few definite statements on many issues concerning POPs can be made. The acute toxicity of both DDT and PCBs after a highly dosed exposure is one of the few hardly contestable statements. The theoretical model on the mechanism through which highly dosed DDT exposure and PCBs exposure leads to severe damage was plausibly formulated and repeatedly tested in labs and in (accidental) field tests. It was never really contested and can therefore count as 'certain knowledge'. Additionally, very detailed knowledge on the development of pest resistances and reduced effectiveness as a result of long-term, large-scale use of DDT was available quite early on.

Concerning **transboundary migration**, there were initially at least two theoretical models in the 1960s to explain transboundary transport. However, both theories – migration through the food chain and through water currents – could not be supported by empirical evidence. Theoretical predictions did not match the empirical findings, and mechanisms of transboundary migration were highly uncertain at that point. In search of alternative theoretical models, scholars began to theorize on *atmospheric* migration in the 1980s. By the late 1980s and early 1990s, evidence of *atmospheric* transport accumulated. The theoretical model on transboundary atmospheric migration was supported by numerous field tests and laboratory studies; as a result, the scientific uncertainty about mechanisms of transboundary transport declined. The emergence of the atmospheric transport model constitutes a turning point in the level of scientific uncertainty on migration. While the level was very high in the 1960s with at least two untested explanatory models, it declined in the 1980s and the 1990s, when a single model was confirmed by different empirical studies.

Theoretical models on **emission sources** of DDT and PCBs had been supported quite early on and proved to be a rather simple scientific task. DDT has been produced in large quantities for the agricultural sector, PCBs have been used in open and closed electronic systems. But even though emission sources of both compounds can easily be identified, quantifying emissions and tracing quantities back to emitters remained and still remains difficult (Li, 1999; Ritter et al., 1995; Voldner and Li, 1995).

Scientific literature is highly at variance regarding **negative effects**. Even though studies suggest negative effects, serious uncertainties remain. This is reflected by both the IPCS assessment report and the assessment report of the LRTAP Working Group on Technology (Ritter et al., 1995; UN.ECE, 1994b,b). Both of the reports emphasize the preliminary nature of the information and the need for more research. The report of the LRTAP-Working Group on Technology states that there are "[. . .] difficulties in determining the role that POPs already in the environment have in sustaining elevated ecosystem levels, and inherent difficulties in obtaining biological effect and epidemiological data; all represent areas of uncertainty which are unlikely to be resolved in the short or medium term." (UN.ECE, 1994a, :20).

The analysis of the scientific literature as well as the official assessment reports allows to conclude that knowledge about negative effects on wildlife and human health from DDT and PCBs was still uncertain when negotiations started in 1997. Either methodological problems allow to question evidence for negative effects, scholars expressed the limitations of their own studies or were refuted by rivaling studies.

Scientific uncertainty has been operationalyzed in chapter 4 according to the number of rivaling models and the reliability of empirical tests. This operationalization can now be applied to the development of scientific knowledge on POPs to show how scientific uncertainty over time and across different scientific sub-issues. The results are summarized in table 5.3.

	1950s	*1960s*	*1970s*	*1980s*	*1990s*	*2000*
Sources and Emissions	%	%	%	%	%	-
Negative Effects	++	++	+	+	+	+
Transport and Migration Patterns	++	+	+	-	- -	- -

TABLE 5.3: Level of Scientific Uncertainty Concerning POPs over Time and Scientific Theme

Uncertainty levels (see section 4.4.1.2: ++ = very high, + = high, % medium, - = low, - - very low)

5.1.4 Stages of Regime Formation

5.1.4.1 Efforts on Domestic Regulation of POPs

Scientific findings on possible negative effects from DDT and the promotion of these findings caused public concern in many countries, which put pressure on policy makers to engage. Especially DDT sparked public and political concern which led to legislative regulation on the agricultural use of DDT in many developed countries. However, the political action on POPs differed across countries in timing and character. While for example the U.S. introduced rather strict domestic legislation in 1972, DDT was still used in the agricultural sector of many countries until 1984. Additionally, some countries set up quota for agricultural use rather than banning DDT as such. Nevertheless, as table 5.5 shows, all negotiating countries had installed some form of regulation on DDT by 1996. The effects of domestic regulation on POPs-emissions are reflected by decreasing emissions during this period (see table 5.5).

Since the release patterns of PCBs are more complex, the issue of PCBs entered the scientific and political debate later than DDT. PCBs were entangled in more diverse production cycles and finding appropriate regulatory measures proved to be more difficult. States began to regulate PCBs domestically from the late 1970s up to the late 1990s. However, as the use of PCBs was more diverse compared to DDT, the regulation differed from state to state. While some states banned or phased out all applications for PCBs, others would still allow the application of PCBs, for example for non-consumer goods or in closed systems where the actual emission of PCBs was unlikely.

5.1.4.2 Early Demands for International Regulation and Agenda Formation

In the early 1980s, discussions within the United Nations Food and Agriculture Organization (FAO) and United Nations Environment Programme (UNEP) led to the development of the 1985 International Code of Conduct for the Distribution and Use of Pesticides and the 1987 London Guidelines for the Exchange of Information on Chemicals in International Trade. Both the Code of Conduct and the London Guidelines included procedures that aimed at improving the availability, thereby permitting countries to assess the risks associated with the use of chemicals (Krueger and Selin, 2002).

Since high concentrations of POPs had been found in the tissue of indigenous people in the Canadian Arctic, the issue was introduced by Canadian officials to the UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). On the basis of the Canadian initiative, the CLRTAP Executive Body initiated an assessment process and installed a Task Force on POPs (Farrell, 2006) in December 1990 to develop a better understanding of POPs for potential future negotiations. The task force reviewed existing findings on substances that had already been suspected by applying a formalized screening procedure which focused on (a) potential long-range transport, (b) toxicity (c) persistency and bioaccumulation. While information on long-range transport seem solid and information on acute toxicity was more or less reliable, assessing persistency and bioaccumulation incorporated severe uncertainty, due to not only data gaps but also by uncertainty about the appropriate model used for assessment (Rodan et al., 1999, :3488).

The Task Force recommended to the CLRTAP Executive Body to take multilateral action on a list of POPs, even though it expressed large uncertainties in its final state of knowledge report (UN.ECE, 1994a). Following this recommendation, the CLRTAP Executive Body installed a Preparatory Group in 1995 to prepare political negotiations within the CLRTAP framework. The group drafted negotiation proposals that already included possible policy action (UN.ECE, 1995). On the basis of the assessment work of the Task Force and the proposals of the Preparatory Group, the negotiation process commenced in January 1997 (UN.ECE, 1997) and continued in four sessions until February 1998 during the plenary sessions of the CLRTAP Working Group of Strategy (Selin, 2000).

5.1.4.3 Regime Negotiations Under CLRTAP

During the initial meeting in January 1997, participants expected short and successful negotiations (Selin, 2000, :160). But despite the general consensus among participating states that an international agreement on POPs would be desirable, the list of POPs to be included into an agreement, how POPs should be regulated (banned, partially banned, phased out, etc.) and how to integrate new substances into the protocol were still left to be discussed (Selin, 2000, :160). The cleavages ran between three groups of participating states: the European Countries, the U.S. and Canada, and the Russian Federation and Ukraine (Selin, 2000).

Both DDT and PCBs were considered crucial since they were of symbolic value for the public and had been among the economically most important POPs. While there was an agreement to include DDT into a protocol on POPs, countries disagreed on the mode of regulation. While most European nations pushed for quick bans on production, use and trade, Italy wanted exemptions to use DDT as a intermediate product for specialized industrial processes. With reference to WHO's recommendations, the U.S. refused trade-regulations for DDT, while the Russian Federation and Ukraine called for exemptions for DDT use for malaria control (Selin, 2000).

PCBs were also on the initial list of POPs under consideration for a protocol. However, the Russian Federation, supported by the Ukraine called, for exemptions on both the production and use of PCBs during the third round of negotiations (Selin, 2000, :165). This maneuver by the Russian Federation caused a set-back in negotiations and made it clear that a quick resolution would not be accomplishable. During two off-schedule Head of Delegations meetings in London in 1998, positions were exchanged and final compromises were achieved on some remaining critical issues. For example, an extra five-year period to phase out use and production was granted to economies in transition. During these same meetings, a compromise was reached on the trade of pesticides, stating that trade should not be regulated by a protocol until a revision five years later. A similar compromise was found for Italy's demand on the production of DDT as a intermediate product (Selin, 2000, :176). These compromises were agreed upon in the closing session and the agreement was signed in in June 1998.

5.1.5 Costs and Benefits of the Regulation of POPs

The previous sections provided a historic account of scientific research and political negotiations of the POPs-issue. However, to test the argument, it is necessary to operationalize costs and benefits of international regulation and to validate the qualitatively obtained insights with data on emissions and exposure. The theoretical argument states that in the case of successful regime formation, costs are expected to be low while scientific uncertainty is high. Furthermore, the argument leads to the expectation that countries show a degree of similarity. Testing the argument against an additional set of data increases the robustness of findings.

5.1.5.1 Costs

In the case of POPs, costs from international regulation are associated with emission cuts. One way to assess costs would therefore be to assess emission data of the signatory states at the time of the negotiations to determine who would face higher or lower costs from international regulation to conclude support or aversion towards international regulation. This would, however, dismiss the main merit of the historical perspective of this case study. Since the historical process tracing revealed that almost all signatory states had already installed national legislation on DDT and PCBs (see section 5.1.3.2 and table 7.2), including data of past emission cuts, because it represents the *additional* costs from international regulation. This follows the logic that a country which already cut its emission to a fraction of the former peak emissions bears lower costs from additional international regulation (and would therefore rather push for regulation) whereas a country with small emission cuts or even an increase in emissions would bear higher costs and rather oppose additional regulation. Additionally, including data from all signatory states is misleading, since many signatory states were rather passive or not even represented during negotiations and therefore, their interests did not shape the agreement. Hence, the focus is on data from states that were active during the negotiations. According to Selin (2000) these were Canada, Denmark, Germany, Italy, the Netherlands, Norway, Russia (Russian Federation), Spain, Switzerland, Ukraine, UK, and USA. (Selin, 2000, :155)

As table 5.4 and table 5.5 indicate, the highest decrease of PCBs emissions and DDT emissions (nearly -95%) appeared in the forehand to CLRTAP Protocol negotiations on POPs. However, especially states from the former Soviet Union increased their emissions on PCBs during that time period. This implies that most negotiating countries expected rather low costs from international regulation on POPs, with slight dissimilarities concerning some former Soviet Union countries.

5.1.5.2 Benefits

As stated in section 5.1.2, benefits are regarded as a function of hazardousness and exposure. Measuring concentration levels in human breast milk has matured as a standard procedure to determine exposure in a given spatial area and serves as a indicator for exposure to PCBs and DDTs. Both the tables 5.6 and 5.7 reflect

Country	**DDT-Emissions 1970**	**DDT-Emissions 1996**	**ΔDDT(t) 1970 – 1996**	**Year of Regulation**
Canada	n/a	n/a	n/a	1972
Denmark	18.00	0	- 18.00	1984
Germany	1652.00	0	- 1652.00	1974
Italy	2178.00	0	- 2178.00	1978
Netherlands	130.00	0	- 130.00	1968
Norway	1.73	0	- 1.73	1970
Russian Federation	6000.00	0	- 6000.00	1992
Spain	1200.00	0	- 1200.00	1972
Switzerland	10.00	0	- 10.00	1972
Ukraine	5150.97	0	- 5150.97	1994
UK	49.62	0	- 49.63	1984
USA	n/a	n/a	n/a	1972

Table 5.4: Change in DDT-Emissions of POPs-Protocol Signatory States and Russia Between 1970 and 1996

Emission Data predominantly rests on the following sources: Breivik et al. (2004); Pacyna et al. (2003); Pacyna (1999). For sources on national legislation, see table 7.1 for details.

Country	**PCBs Emissions in 1970**	**PCBs Emissions in 1996**	**ΔPCB (metric tons) 1970 - 1996**	**Year of Regulation**
Canada	n/a	n/a	n/a	1977
Denmark	24971	1026	- 23945	1986
Germany	402160	42462	- 359698	1972
Italy	270757	6054	- 264703	1970s
Netherlands	65823	250	- 565573	1970s
Norway	19598	408	- 19190	1981
Russian Federation	2094	8072	+5978	1992
Spain	170541	8721	- 161820	1976
Switzerland	n/a	n/a	n/a	1986
Ukraine	1181	3043	+1862	–
UK	282443	3706	- 278737	1981
USA	114000	0	- 114000 [8]	1977
SUM	**2308834**	**119121**	**- 2189713**	

Table 5.5: Change in PCBs Emissions Between 1970 and 1996 in Negotiating States

Emission Data predominantly rests on the following sources: Breivik et al. (2004); Pacyna et al. (2003); Pacyna (1999). For sources on national legislation, see table 7.2 for details. The table includes only states that were highly active during negotiations (Selin, 2000, :155). For a more conclusive overview, see table 7.3 exposure to PCBs and DDT. To fully evaluate benefits, both exposure *and* harmfulness have to be considered. As subsection 5.1.3 shows, the aspect of whether and to what degree PCBs and DDT posed harms to human health was highly controversial. Both PCBs and DDT were associated with different forms of cancer. This is reflected by the assessment work preceding the negotiations of the POPs Protocol. The International Agency for Cancer Research categorized PBCs as 'probable carcinogens (category 2A)' and DDT as 'possible carcinogens (category 2B)'. The IACR-category 2A implies that there is only limited evidence for carcinogenicity in humans, while experimental animal trials imply carcinogenicity. The IACR category 2B implies that there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals.

Both of the substances have been associated with several other negative consequences such as reproductive failure and immune suppression. However, as implied by the literature analysis in section 5.1.3 and highlighted by the assessment reports, the evidential basis for other negative consequences is at least as uncertain as for cancer. Since there is only limited evidence for harmfulness for both PCBs and DDT (which is also reflected by the literature analysis in chapter 5.1.3), the harmful character of both PCBs and DDT is uncertain. Hence, the value for harmfulness varies between 0 (not harmful) and 1 (harmful). As benefits are a function of both exposure and harmfulness, countries can be assumed to estimate their benefits from international regulation as being either 0 (if the substances are not harmful) or their individual level of exposure (if the substance is harmful).

5.1.5.3 Costs & Benefits

Data on exposure of both DDT and PCBs is unfortunately not available for all countries and the whole time span. This prohibits strong conclusions about how the configuration of costs and especially benefits changed over time. However, data allows to conclude that emissions for substances decreased significantly, with the exception of the Russian Federation. This allows to conclude that – with the exception of the Russian Federation – all negotiating states expected similarly low

Country	**PCBs Concentrations (μg /kg milk fat)**	**Year**	**Source**
Canada	n/a	n/a	n/a
Denmark	91	1999	(WHO, 2000)
Germany	220	1999	(WHO, 2000)
Italy	253	1999	(WHO, 2000)
Netherlands	192	1999	(WHO, 2000)
Norway	119	1999	(WHO, 2000)
Russian Federation	126	1999	(WHO, 2000)
Spain	241	1999	(WHO, 2000)
Switzerland	n/a	n/a	n/a
Ukraine	136	1999	(WHO, 2000)
UK	n/a	n/a	n/a
USA	54	1999	(WHO, 2000)

Table 5.6: PCBs Exposure
Data on Exposure predominantly rests on the following sources: (WHO, 2000). The table shows only states that were active during the negotiations on the POPs-Protocol. (Selin, 2000, :155).

Country	**DDT Concentrations (μg /kg milk fat)**	**Year**	**Publication**
Canada	385	1986	(Smith, 1999)
Denmark	238	1992	(Smith, 1999)
Germany	531	1991	(Smith, 1999)
Italy	2200	1985	(Smith, 1999)
Netherlands	n/a	n/a	n/a
Norway	910	1982	(Smith, 1999)
Russian Federation	2000	1989	(Tsydenova et al., 2007)
Spain	296	1991	(Smith, 1999)
Switzerland	n/a	n/a	n/a
Ukraine	1072	1996	(Smith, 1999)
UK	490	1991	(Smith, 1999)
USA	770	1989	(Smith, 1999)

Table 5.7: DDT Exposure in 1986 and in 1991

costs from international regulation. Most emission cuts had been implemented through domestic regulation in forehand. On the other hand, benefits from regulation were still uncertain since the harmfulnes of PCBs and DDT had not been sufficiently proven. Since, however, the majority of scientific studies and assesment reports suggested *possible* negative health effects, it can be assumed that countries considered the possibility of potential negative health effects. And even though exposure rates varied across actors, all negotiating states experienced some form of exposure. The combination of possible harmfulness form POPs, certain knowledge of transboundary transportation and certain knowledge of existing exposure levels allow to conclude that negotiating states anticipated benefits from international regulation. Additionally, as the qualitative analysis of the political negotiation process shows, states negotiated exception rules for countries that anticipated increasing costs (through increasing emissions of POPs), such as the Russian Federation.

5.1.6 Conclusion – Costs, Benefits and Uncertainties

The analysis of the CLRTAP Protocol on Persistent Organic Pollutants shows that states formed an international regime *despite* severe scientific uncertainty. Selin (2000) states that "The participants did not have a clear image of all possible pay-offs when they began negotiating [...]"(Selin, 2000, :153). The CLRTAP Task Force on POPs, assigned with the review of the scientific literature as an assessment work for future negotiation states in its final report that "For the large number of substances included in the 'POP family', inadequate emissions inventories for POPs, incomplete understanding of POP transport processes and mechanisms within the ecosystem, difficulties in determining the role that POPs already present in the environment have in sustaining elevated ecosystem levels, and inherent difficulties in obtaining biological effect and epidemiological data remain; all of them represent areas of uncertainty which are unlikely to be resolved in the short or medium term." (UN.ECE, 1994a, : 92). This statement summarizes the analysis of the scientific literature in subsection 5.1.3 which shows that some sectors of scientific knowledge were still highly uncertain while others were covered by well-established knowledge.

Country	**DDT Emissions (1970 in metric tons)**[a]	**DDT Emissions (1996 in metric tons)** [b]	**DDT-Concentrations between 1986 and 1991 (μg /kg milk fat)**[c]
Canada	n/a	n/a	n/a
Denmark	18.00	0	91
Germany	1652.00	0	220
Italy	2178.00	0	253
Norway	1.73	0	119
Russian Federation	6000.00	0	126
Spain	1200.00	0	241
Switzerland	10.00	0	n/a
Ukraine	5150	0	136
UK	49.62	0	n/a
USA	n/a	n/a	54

Table 5.8: DDT Emission and Exposure between 1970 and in 1996

[a]Source: Breivik et al. (2004); Pacyna et al. (2003); Pacyna (1999)
[b]Source: Breivik et al. (2004); Pacyna et al. (2003); Pacyna (1999)
[c]Source: Smith (1999); Tsydenova et al. (2007)

Country	**PCB-Emissions (1970)**[a]	**PCB-Emissions (1996)**[b]	**PCB-Concentrations (1999)**[c]
Canada	n/a	n/a	385
Denmark	24971	1026	238
Germany	402160	42462	531
Italy	270757	6054	2200
Netherlands	65823	250	
Norway	19598	408	910
Russian Federation	2094	8072	2000
Spain	170541	8721	296
Switzerland	n/a	n/a	n/a
Ukraine	1181	3043	1072
UK	282443	3706	490
USA	114000	0	770

TABLE 5.9: PCB Emission and Exposure between 1970 and in 1996

[a]Source: Breivik et al. (2004); Pacyna et al. (2003); Pacyna (1999)
[b]Source: Breivik et al. (2004); Pacyna et al. (2003); Pacyna (1999)
[c]Source: NRC (1979a)

In the light of these hypotheses, we would expect that the formation of the POPs-regime was facilitated because (a) there was sufficient knowledge available that costs of forming a regime would remain low and (b) scientific uncertainty would mainly affect consequences for human health and/or wildlife. We would also expect that involved states who expected high costs from regulation with certainty would oppose a regulation or call for a milder form of regulation. Concerning the role of new scientific knowledge, we would expect that the issue itself would find its way on the international agenda as a consequence of evidence for its transboundary character has been found beyond the stage of speculation. We would therefore expect that political action would follow scientific findings. Furthermore, we would expect that a regime formation process only advances if new scientific knowledge reveals that benefits exeed or *might exeed* the costs from international regulation.

The process-tracing analysis reveals that countries began to domestically regulate DDT between 1970 and 1985. This corresponds with the time span when scientific evidence about potential negative health effects accumulated. Additionally, DDT proved to be more and more ineffective for large-scale pest control as resistance of pests increased during the same time span and its economic relevance declined. Similarly, countries installed regulation on the production and use of PCBs between 1975 and 1986, even though PCBs were not regulated as strictly as DDT. And as emission data on DDT and PCBs indicates, emissions dropped sharply between the 1970s and 1990s as a result from domestic regulation. During that time span, POPs were a purely national matter, since knowledge on transboundary migration was scarce.

This changed in the early 1990s when findings of high POPs levels in remote areas could be explained sufficiently by the scientific theory on atmospheric transport. While high residues of POPs in the Arctic had been known since the 1970s, rivaling theories could not explain the residues. The conclusive theory on atmospheric transport that emerged in the 1990s pushed the issue to the international level and negotiations on POPs commenced in 1997. This indicates how new scientific knowledge turned an issue from a purely domestic issue to one of international cooperation, which corresponds to the second argument in chapter 3. New scientific knowledge reshaped the perception of the issue and knowledge about the transboundary character of POPs motivated states to negotiate the international regulation of the issue.

Secondly, as data on emissions and domestic regulation indicates, countries could expect low additional costs from regulating DDT and PCBs since the emission levels for both had already dropped significantly before negotiations started. Thirdly, an argument about similarity (or symmetry, as Barrett (2001) calls it) can be made. As data on emissions, as well as data on exposure reveals, states shared a rather similar cost-benefit-configuration. And last, the process of negotiations shows how dissimilarities were leveled (or how cooperation was 'bought') on the issue of PCBs, on which a compromise was found to evoke the participation of the Russian Federation and Ukraine. The following can be concluded: when negotiations started in 1997, the cost-benefit-configuration for negotiating states was conducive towards regime formation. While benefits were still uncertain, costs from international regulation were low. Dissimilarities between states were leveled through compromises. Table 5.10 summarizes the progress of the scientific process, the deducted cost-benefit configuration and the political process.

However, the analysis excludes aspects that might be crucial for a conclusive explanation of the role of scientific uncertainty and the emergence of the POPs regime. As the analysis shows, most countries had already taken regulatory steps concerning POPs which lowered the costs of an international agreement. Therefore, to conclusively investigate policy-making under the condition of scientific uncertainty, policy-making that led to national regulation has to be considered. In the light of existing scientific uncertainty, why did states take domestic action to regulate POPs? Even though this process was not thoroughly investigated, the analysis reveals at some points how selective scientific findings were picked up by actors of civil society, who exerted pressure on domestic political decision-makers in some states. For example, Carson (1962)'s book served as a reason for NGOs to push for domestic regulation, even though the publication appeared at a time when POPs were not fully understood. The consequential question to be asked would

	Before 1960	*1960-1985*	*1986-1995*	*1996-2005*
Scientific Process	Conclusive knowledge about acute toxicity for humans of high-dosed DDT. Limited knowledge on residues and on effects of low-dosed latent exposure. Accumulating evidence for pest-resistance against DDT and other POPs. Little knowledge on toxicity of PCBs.	Accumulating evidence for harmful effects of POPs, especially cancer and hormonal effects. Findings remained however tentative. Inconclusive explanations for transboundary movement of POPs.	Conclusive theory for transboundary movement of POPs and empirical confirmation. Little scientific progress on negative effects from POPs	Remaining uncertain knowledge about harmful effects from POPs. Further refinement and confirmation on transboundary migration patterns.
Perceived Cost-Benefit-Configuration	Low benefits, high costs from regulation.	Uncertain benefits, uncertain costs from international regulation.	Low costs, uncertain benefits.	Low costs, uncertain benefits.
Expected Political Reaction	Business as usual.	Demand for more scientific knowledge, international coordination of scientific research.	Demand for international regulation.	Demand for international regulation.
Observed Political Process	No efforts on an international level.	Domestic regulation in many countries. Decreasing emissions for most POPs.	1987: London Guidelines to share scientific infor-mation on POPs. 1990: Early demands for the international regulation by official political actors and NGOs.	Negotiations towards an international agreement on POPs began in 1997 and concluded in 1998 with an international agreement. Ratification was reached in 2003.

TABLE 5.10: Milestones in Scientific Research and Political Action on POPs

then be: when and why does civil society push for legislation on an environmental issue that is still scientifically uncertain? Future research should address these questions.

Additionally, the study exclusively focuses on two specific POPs – DDT and PCBs. It can be argued that the emergence of the POPs regime could be conclusively explained if all POPs were included, since states could have bargained package-deals across POPs. However, DDT and PCBs have been selected for several reasons. First of all, both POPs had been at the center of debates among POPs and both of them were most present throughout the negotiating proces (Jones and De Voogt, 1999).

The official assessment work of the CLRTAP Task Force and Preparatory Group initially identified 18 POPs as possible candidates for international regulation. However, only 14 substances entered the negotiations. A full account of the regime formation process could investigate why the initial list was narrowed down and why some POPs were excluded from the list. According to the theoretical argument in chapter 3, we would expect that for these substances, the cost benefit configuration was not conducive.

Furthermore, the study focuses on the mere formation of the POPs agreement. Analyzing the development of the regime, its consequences, state compliance and the integration of additional substances provides a great area for future research. Especially the future developments of scientific knowledge and the resulting integration of additional substances are of interest to further test the theoretical argument on new scientific knowledge.

This ties in with the development of other regulatory initiatives on POPs as the UNEP Stockholm Convention on POPs from 2001, which is broader in participation. First of all, there is an argument that the foresight of the soon-to-follow negotiation process to the Stockholm Convention pushed CLRTAP states to reach an agreement (Selin, 2000). Secondly, a comparison between the two multilateral environmental agreements in the light of the argument could reveal additional insights on the role of scientific uncertainty and new emerging scientific knowledge. While the first point could be an alternative explanation, the second aspect constitutes an additional field for future research.

The narrow focus of the case-study is however justifiable in the broader context of this work. The aim of this study is not to deliver a full explanation of each single case. The aim is rather to test the theoretical argument and to investigate the role of scientific uncertainty through comparing different occasions where countries did or did not agree on institutionalized cooperation.

In conclusion: The case of the CLRTAP Protocol on POPs partially supports the argument. Speculations on possible harmful effects from constant low-dose exposure led to domestic awareness, and in some countries to national legislation on the issue. Knowledge on the transboundary nature of POPs pushed the issue to the international agenda. By the time the issue was negotiated, most countries had already installed domestic regulation and the additional costs can be considered to be low. Countries negotiated compromises on issues that were still critical since countries still faced high costs from regulation.

5.2 The Regime on the Protection of the Stratospheric Ozone Layer

> "The Protocol was negotiated under intense uncertainty regarding both the risks of ozone depletion and the feasibility of the agreed measures [. . .]."
>
> Edward A. Parson *Protecting the Ozone Layer*

The case stratospheric ozone protection is one of the most intensely studied cases of institutionalized international cooperation. While both the knowledge-based and interest-based approaches claim for themselves high explanatory value (Barrett, 2001; Haas, 1992a), not any of the accounts offer a full and convincing explanation. Therefore, the case is highly relevant for testing an integrated theoretical framework that combines knowledge and interests. According to the theoretical argument, we would expect that a conducive configuration of scientific knowledge (the independent variable) led to the successful formation of an international regime (the dependent variable). Furthermore, we would expect that a regime not to form before new scientific knowledge had turned an obstructive configuration into a conducive configuration.

The ozone layer absorbs and reflects nearly all harmful ultraviolet radiation (UV) in sunlight and is therefore crucial for the life on earth as we know it. Approximately 90% of atmospheric ozone accumulates in the stratospheric layer at an altitude of approximately 15 - 30 km (Parson, 2003). Ozone is a chemical bond of three oxygen atoms (O_3). Chlorofluorocarbons (CFCs), in turn, serve as a catalyzer that breaks up ozone into O_2, rendering the UV-screening-function.[9] Enhanced UV-radiation damages human skin cells, eyes and has effects on plants and animals. CFCs have been industrially used since the 1960s for many different

[9] CFCs are broken into chlorine through photochemical processes. Thus, CFCs lead to a loss of stratospheric ozone and an increase of harmful UV-radiation on the earth's surface.

purposes, such as propellants in spray-cans (aerosol use), as cooling liquid in refrigerators and air-conditioners (non-aerosol use) or in industrial cleaning processes (Parson, 2003, :32).

Several international documents cover the protection of the ozone layer: The Vienna Convention for the protection of the ozone layer (1985), the Montreal Protocol on substances that deplete the ozone layer (1987), the London Amendments (1990), the Copenhagen Amendments (1992) and the Beijing Amendments (1999). The Vienna Convention was negotiated between 1982 and 1985 among the major producer states and developing countries. Its non-binding character and its ambiguous language[10] made it a rather weak agreement. The agreement, however, did contain commitments on further research efforts regarding the issue. Furthermore, the Convention served as a framework and institutionalized further negotiation rounds which resulted in the Montreal Protocol of 1987. The Protocol marked a significant change in ozone diplomacy. With a broader participation, including non-governmental organizations, industry representatives and developing countries, negotiations led to a protocol which was added to the Vienna Convention that included a list of different CFCs to be regulated, as well as binding commitments to production cuts and consumption cuts. The additional Amendments (London (1990), Copenhagen (1992) and Beijing (1999)) broadened the list of CFCs that were regarded as ozone depleting and tightened roadmaps and schedules for cuts in production and consumption of CFCs. Since this research is primarily concerned with regime formation, this subsection rather focuses on the Vienna Convention and the Montreal Protocol and does not consider additional amendments.

5.2.1 Defining Costs, Benefits and Uncertainties of CFCs

CFCs are problematic due to their ability to catalyze and destroy stratospheric ozone. In the light of current knowledge, the evidential chain is straightforward: CFCs- emissions lead to ozone loss which leads to increased UV-radiation, which,

[10] Countries committed to take "appropriate measures" to address the ozone issue

in turn, causes adverse effects on human health (Diffey, 2004; Ichihashi et al., 2003) and ecosystems (Paul and Gwynn-Jones, 2003). As described in chapter 4, costs are to be conceptualized as direct economic costs, while benefits from regulation ought to be conceptualized as reduced vulnerability towards the environmental threat as such. In the case of stratospheric ozone, this work can build on the analysis of Sprinz and Vaahtoranta (1994). They use the negotiations of the Montreal Protocol as case study and conceptualize costs in the case of ozone depletion as CFCs production and its consumption in relation to a country's gross national product (GNP). They assume that the higher a country's consumption of CFCs per unit of gross national product is, the higher a countries abatement costs can be expected (Sprinz and Vaahtoranta, 1994, :88). Vulnerability, in turn, is conceptualized as incidences of skin cancer (Sprinz and Vaahtoranta, 1994, :87).

Though scientific uncertainty is recognized by many scholars of the ozone-case (Haas, 1992a; Parson, 2003; Skodvin, 2000)[11], its role in negotiations has not been thoroughly studied yet. The theoretical argument in section 3 calls for an integration of scientific uncertainty and for a consideration of the configuration of scientific uncertainty.

The Vienna Convention in combination with the Montreal Protocol represents a multilateral agreement with substantial cuts in production and consumption of CFCs. Secondly, as emphasized by previous research, the issue has been plagued by a high degree of scientific uncertainty (which is to be elaborated further in this subsection). Since a multilateral binding agreement that was negotiated under the impression of scientific uncertainty is observable, we would expect (following the theoretical argument) a conducive cost benefit configuration for this case. The theoretical argument argues that states are willing to form international environmental regimes if they collectively share a similar conducive configuration of knowledge about costs and benefits. If the argument holds, we would expect that states anticipated low direct economic costs, while benefits in the form of reduced vulnerability were considered to be uncertain. This means that costs from cutting

[11] Even though Sprinz and Vaahtoranta (1994) mention the aspect of scientific uncertainty, they neglect its role in favor of their theoretical and methodological argument.

consumption and production of CFCs have been low or were expected to drop significantly by the time the agreement was negotiated and signed.

Concerning changing scientific knowledge, we would expect that new scientific knowledge changed the profile from obstructive to conducive: new scientific findings should indicate that economic costs from cutting production and consumption can be expected to be lower than previously expected.

5.2.2 The Outline of the Case Study

The aim of this case study is to retrace developments and shifts in scientific knowledge in order to determine how the perception of the issue at stake changed over time. Secondly, the study aims at identifying what aspects of the issue were known or unknown at the time political decisions were made. To identify in a first step which research themes dominated during different time-spans, the scientific journals *Nature* and *Science* are scanned for publications on the issue, using the key-words *ozone depletion, ozone destruction, CFCs*, *Chlorofluorocarbon* and a combination of these keywords. According to the argumentation in chapter 4, different types of knowledge are relevant to determine either costs or benefits from multilateral cooperation. Identifying what types of knowledge dominated during a time span allows to conclude which topic was in the scientific spotlight at what point in time. To reduce the vast amount of literature, an additional citation analysis using 'CiteSpace' was conducted. The analysis resulted in 58 articles that were included in this study. For an overview, see the appendix.

In addition to the primary sources of scientific literature, this study rests on the vast body of secondary literature that covers both the scientific and political process. The Vienna Convention and the Montreal Protocol are probably the most prominent multilateral environmental agreements in the literature on international environmental cooperation. The regime has been hailed as a great success story and many scholars use it to conduct case study research on regime formation. The amount of social science literature on the process that led to the agreement is vast and hence, this case study can rely on existing works. Above all, the study of Edward Parson (2003), which produced a 300 pages book and filled some 12-feet of bookshelf space in primary material[12] has to be mentioned as a most thorough and detailed work that investigates the political and scientific processes. His expertise entered this case study also through an expert interview. Besides the mentioned work, the works of Benedick (1998), Dimitrov (2006), Skodvin (2000) and Haas (1992a) have been included as basis for a content analysis. The mentioned contributions all focus on the role of scientific findings within the process of negotiations and - at least partially - acknowledge scientific uncertainty.

Though this study uses to a great extend secondary literature to retrace the empirical processes, some well-known contributions that address the Montreal Protocol (as for example Barrett (2001)) have not been included. These contributions mainly use the Montreal Protocol to test a theoretical argument or modeling accounts and do not deliver new empirical accounts on how the different processes developed over time.

Besides secondary literature, this case study is based on diverse assessment reports that have been carried out by different scientific agencies and research circles. These include the U.S. National Aeronautics and Space Administration (NASA), the US National Academy of Science (NAS), the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP).

To capture the political process, the case study rests on the one hand on the mentioned contributions from secondary literature. Additionally, some contributions are added that focus explicitly on the political process (for example Benedick (1998)). On the other hand, the political deveolpements are retraced from the official documentation of the negotiation process, made available through UNEP. The following analysis rests on the mentioned body of literature.

[12] Available at the Harvard library

5.2.3 Stages of Scientific Knowledge

5.2.3.1 Sources of Ozone Depletion

Basic knowledge on stratospheric ozone and its ability to absorb UV-radiation has evolved since the late 19th century (Bhattacharya et al., 2012) and intensified during the 1920s and 1930s (Chapman, 1930). The combination of Gotz et al. (1934)'s model on the vertical distribution of atmospheric ozone and Chapman (1930)'s theory about UV-absorbation by ozone provided the basic understanding that stratospheric ozone absorbs most of the harmful UV-radiation. Findings in the 1950s, however, revealed deviations between model predictions and crude empirical measurements of stratospheric UV-radiation. The deviations did not directly hint to ozone destruction, nor to an anthropogenic source for deviations, but they spurred further research interest in atmospheric ozone and possible catalyzers as well as possible sinks. Three substances were assumed to potentially catalyze stratospheric ozone: nitrogen oxide (NO_x), chlorine (Cl) and vaporized water. In simplification, the three substances have the potential to bind oxygen atoms and break up ozone (O_3) into molecular oxygen (O_2) which does not absorb UV-radiation in the same way as ozone (Bhattacharya et al., 2012). Though the basic chemical mechanisms were known, it was unclear if and how they were working under stratospheric conditions. Furthermore, it was unclear through which pathways the three substances would enter the stratosphere, where they could potentially destroy ozone.

Plans of several governments to establish a fleet of civil supersonic transporters (SST) - such as the British/French Concord - during the 1960s have raised the question on the effects of stratospheric aviation for the ozone layer. On the basis of Hunt (1966)'s model on a catalyzing function of water vapor, it was feared that vapor from SST exhaustions would considerably deplete stratospheric ozone (Harrison, 1970). An even greater concern grew from NO_x in SST-exhaust. Since Crutzen (1970) showed a catalyzing (and therefore destructive) effect on ozone from NO_x, scholars were alarmed by the planned 200 SSTs (Johnson, 1972; Johnston, 1971). The concerns of NO_x and water vapor were weakened since SST-plans had been realized on a much smaller scale than originally planned and new scientific findings revealed that water vapor from exhaust-fumes would have the *opposite* effect of what was previously anticipated. Newer models and experiments suggested that water vapor would actually increase stratospheric ozone (Fabian, 1978).

Concerns about NO_x reappeared on the scientific agenda, since the substance became widely used as soil fertilizer (Shapley, 1977; Turco et al., 1978; Whitten et al., 1980). However, the source from soil was found to be very small. Additionally, a large-scale upwards travel of NO_x in significant amounts seemed unlikely. Both water vapor and NO_x vanished from the scientific debate in the late 1970s and early 1980s and research started to exclusively focus on possible sources of chlorine in the stratosphere.

Even though the concerns about ozone-destruction from SSTs turned out to be negligible, the SST-debate raised scientific and public interest in stratospheric ozone and ozone depletion (Parson, 2003, :30). Several research groups formed and US government agencies established scientific research networks to assess and evaluate the issue. The first report on the issue was released by the Climate Impact Assessment Program (CIAP), a branch of the US National Academy of Science (NAS). The report focused on the effects of SSTs for ozone destruction by sponsoring extensive basic research.

While research on SSTs was deliberately directed on identifying sources for ozone depletion, the discovery of surface-emissions of CFCs as a potential source for chlorine in the stratosphere was rather coincidental. Lovelock et al. (1973) used CFCs for their extreme stability as tracers for mass transfer processes in the atmosphere and oceans. They measured considerable amounts of CFCs in the atmosphere over the ocean's surface, but stated that "[. . .]the presence of these compounds constitutes no conceivable hazard (Lovelock et al., 1973, :194). Additionally, they assumed at first natural sources, such as sea salt spraying. Only a year later, Lovelock (1974) corrected this assumption on the basis of Molina and Rowland (1974)'s findings of a chlorine-ozone reaction and urged for further research. Lovelock (1974) found natural sources to be small and stable and therefore, he excluded natural reasons for high concentrations. The source and fate of CFCs were still unknown (Parson, 2003) during that time period.

Inspired by the publications of Lovelock (1974)'s article in *Nature* on the fate and half-life of CFC-emissions in the environment, Rowland and Molina (1975) began to study possible atmospheric sinks for ozone. They assumed that emitted CFCs should either accumulate or be broken down through chemical processes. However, the results remained puzzling, since no relevant atmospheric sink was identified. CFCs-concentrations did not accumulate indefinitely and no relevant tropospheric sink could be found. At the same time, CFCs were still emitted in large quantities. Consequently, the fate of CFCs had to be located somewhere else. (Rowland and Molina, 1975) claimed that CFCs traveled upward through the stratosphere until they released chlorine under the influence of strong sunlight, which would catalyze ozone. On the basis of laboratory work, Rowland and Molina (1975) developed the first theory on significant stratospheric ozone depletion through CFCs (Parson, 2003, :23ff). Their hypothesis was underpinned by three points: their long half-live allowed CFCs to mix in the troposphere and move upwards to the stratosphere. Second, high solar radiation in the stratosphere breaks up CFCs to release chlorine atoms which, in turn, catalyze ozone. Third, continuous worldwide CFCs emissions would sincerely deplete the ozone layer (Parson, 2003, :31).

Another related scientific discussion on chlorine in the stratosphere developed in parallel: While SSTs vanished from the ozone-debate, stratospheric chlorine injection through space-shuttle exhausts entered the debate. Hydrochloric acid (HCl) from space-shuttle exhausts was assumed to release chlorine into the stratosphere. Though researchers found only small effects, it drew further attention to the chlorine-ozone reaction in the stratosphere and the models that emerged from the research on space-shuttles, as well as SSTs, were used and refined by many scholars that investigated the issue.

The research efforts during the 1970s, as well as the collective assessment works, led to an improved understanding of stratospheric chemistry. Furthermore, it identified the ozone-depleting mechanism of anthropogenic CFCs, a mechanism that remained unchallenged further on in the scientific debate. While Rowland and Molina (1975)'s hypothesis was tested and refined repeatedly, it remained in principle unchallenged. The mechanism through which CFCs would break down under the influence of intense solar radiation in the stratosphere and release chlorine which would catalyze and therefore deplete ozone was well understood and reconfirmed multiple times by different scholars. The model was adopted into literally all assessment work and by the early 1980s, no one within the scientific community seriously questioned this model.

5.2.3.2 Extent-Intensity: Assessing and Projecting Ozone Loss

While most research confirmed the existence of the mechanisms of ozone-depletion through CFCs as presented by Molina and Rowland (1974), scientists struggled extremely to quantify actual ozone depletion and to directly observe the catalytic process (Parson, 2003)[13]. Stratospheric ozone concentrations have a natural seasonal and spatial variation. One of the main challenges was therefore to analytically separate natural causes for variations from anthropogenic causes and the release of CFCs.

These difficulties led to a confusing number of estimates of ozone-loss by different researchers and institution. In 1975, the NAS claimed optimistically that "the magnitude of [ozone] decrease can now be reasonably well predicted" (Dimitrov, 2006, :52), a claim that was to be proven wrong over the next several years. In 1975, the NAS provided a first 'most probable' estimate of ozone-loss under steady-state production of 6-7.5% (NRC, 1975), though the report stressed the lack of knowledge about alternative mechanisms through which ozone could be catalyzed. In contrast to the statement in 1975, the NAS report from 1976 states that "[. . .] while our knowledge of stratospheric ozone has become extensive over the last

[13]The first accurate quantity-estimation of ozone depletion was not feasable until 1989 (see: Atkinson et al. (1989)).

years, it should be apparent from the discussion [in this report] that significant uncertainties remain". The report repeats a 7% ozone loss, however quantifies a combined uncertainty measure of "at least" 2-20% (Parson, 2003, :38).

A year later, in 1977, the U.S. National Aeronautics and Space Administration (NASA) published its first assessment report which proclaimed an ozone loss under steady-state production between 10-17%. For the report, researchers calculated ozone loss using nine existing 1D-models with the same data-set and compared results. This method also offered an uncertainty range across the differences between models. In 1979, the NASA-figures were revised by a second interim report of the NAS which stated a 16.5-20% loss in ozone by using different plausible data-sets in one model (NRC, 1979a). The same year, NASA again published a report in which ozone loss ranged from 15 to 18%. Both institutions revised their figures on the basis of an improved understanding of chemical kinetics and state-of-the-art models. In 1982, the NAS published new figures and claimed a 5% loss and abstained in its report from 1984 to deliver new figures due to the persistent uncertainties (NRC, 1982).

This confusion was even further enhanced by discrepancies between model predictions and actual measurements. In 1986, the NASA-report states that the actual quantity of ozone was 30-50% higher than models predicted (Dimitrov, 2003, :55). The worldwide ozone loss which was previously claimed could not be verified, and controversy arose whether it was real or simply an artifact of a deteriorating satellite instrument. These controversies remained unresolved through 1986 and 1987 and represented the most acute scientific uncertainties under which the Montreal Protocol was negotiated and signed. The confusion continued during the late 1980s and were not resolved until the early 1990s when the WMO/UNEP-assessment published accurate numbers (Parson, 2003, :66).

5.2.3.3 Consequences of Stratospheric Ozone Depletion

Sparked by speculations on ozone loss from SSTs, researches stated to consider possible consequences. In the beginning, they drew catastrophic scenarios, reaching from catastrophic climatic change and new sudden ice ages (Hampson, 1964) to the extinction of species (Berkner and Marshall, 1965). The studies were however criticized since the were based on unrealistic assumptions, such as a complete loss of stratospheric ozone.

Research during the 1970s provided more realistic scenarios about possible effects from current-state CFCs-emission and identified three areas of possible effects: marine life, plants and human health (Dimitrov, 2006, :59ff). With regard to marine life, the NAS report from 1976 claims negative impacts on aquatic organisms, especially phytoplankton and zooplankton, both on the bottom of the maritime food chain and therefore crucial for all maritime life. However, the report identifies numerous sources of uncertainties. The report is even more speculative about the effects on plants and agriculture. According to the report, future developments of plant vegetation depends rather on future developments in the agricultural sector than on future emissions of CFCs (NRC, 1976).

Even though reports on negative effects on plants and marine life found their way into all NAS assessment work, the focus shifted more and more towards negative human health effects. Increased UV-radiation was connected to eye damage (such as increased risk of eye cataract), immune system disorder and, most prominently, different forms of skin cancer. In principle, the link between solar radiation and skin cancer had been established since the early 1920s (Hall, 1950) and research advanced during the 1960s and 1970s as methods and instruments improved. The first assessment report on the impact of stratospheric flights already reported a possible increase of skin cancer due to ozone loss (Climatic Impact Committee, 1975). Even though other health effects were related to increased UV-radiation, skin cancer remained the main issue of concern. The NAS-report from 1975 states that 1% ozone loss would lead to 2% increase in skin cancer. The report however points to the speculative and uncertain character of this figure (NRC, 1975, :11ff).

The statement was weakened in the report of 1976 that states that "We find that an increase of melanoma[14] deaths is likely but not certain, to occure as a consequence of a continuing increase in the rate at which DUV[15] received at the ground accumulates." (NRC, 1976, :94). This notion of uncertainty only changed slowly over the years. The NAS-assessment report from 1982 emphasizes that melanomas are undoubtedly related to sunlight, but the relationship is complex and only crude estimates can be made for the increased cancer risk as a result for any given increase in UV radiation (NRC, 1982). In its 1983 update, the NAS repeats its view that UV-radiation is likely to cause melanomas, however data does not reveal the actual mechanism (NRC, 1984). Even though neither the exact mechanism nor the actual quantity could be estimated, all evidence hinted to a qualitative link between increased UV-radiaion and skin cancer rates.

5.2.3.4 Alternatives and Substitutes

CFCs were widely used during the 1960s and 1970s and all indicators pointed to a rather increasing use. They were mainly used either for aerosol uses - as propellants or blowing agent in packaging - or in non-aerosol uses - as refrigerants. Alternatives for aerosol uses - such as hydrocarbons, ethers and nitrous oxide were already known before CFCs became an issue of concern. Even though those substances could be produced at lower costs, CFCs shared some features that made them preferable: they were stable, had no odor and produced a uniform fine spray (Parson, 2003, :32). As a reaction to an emerging U.S. ban of aerosol use in the early 1970s, researchers (especially from the industry-sector) spent much effort in improving the characteristics of alternative substances. By the mid-1970s, CFCs could be replaced for nearly all aerosol applications, either through innovations on comparable substitutes or through the adaptation of technical processes.

Considering non-aerosol use, the picture looked more puzzling. Before Molina and Rowland (1974)'s publication, there seemed no reason to substitude CFCs. On the contrary: CFCs were on the rise since they had replaced highly flammable or

[14] Which is an uncommon, but highly lethal form of skin cancer (Parson, 2003, :87).
[15] A sub-spectrum of UV-Radiation.

hazardous substances in refrigerating units. After environmental concerns entered the picture, it was long believed that substitutes for non-aerosol uses of CFCs were technically infeasible and would stay technically infeasible for an unforeseeable period of time. Research on alternatives for non-aerosol uses progressed slowly. This notion was also expressed both by the assessment report of the Task Force on Inadvertent Modification of the Stratosphere (IMOS) in 1975 and the NAS-report from 1976 (NRC, 1976). Both reports make only vague and pessimistic statements about future findings of adequate substitutes. Research on alternatives was mainly industry-driven and assessment work had to rely on industry findings. During that time, all known potential candidates for the replacement of non-aerosol uses of CFCs faced serious problems and experts merely disagreed on the magnitude of the problems and the time-span necessary to solve them.

However, in 1978, industry representatives announced that, in theory, HCFC 22, HFCs and HCFCs could replace many CFCs even for non-aerosol uses. But at the same time, industry representatives emphasized that, economically, potential alternatives could not compete with CFCs as the were estimated to be twice to five times as costly as CFCs. Additionally, commercializing alternatives required extensive safety testing that was estimated to take 5-10 years. The pessimistic view was rendered in 1986 when industry officials announced that HFCs and HCFCs were suitable substitutes that could replace CFCs in nearly all uses, though to a considerably higher price. This view was confirmed by a broad majority of involved firms. Interestingly, the actual scientific knowledge had not changed between 1980 and 1986, but the conditions under which they were presented had changed, a fact that will be further elaborated on in section 5.2.6.

The publications on CFCs alternatives in 1986 were followed by more and more technical innovations and the former pessimism about the feasibility of CFCs alternatives quickly changed within few years.

5.2.3.5 Summary: SSTs, Chlorine and Scientific Spill-Overs

Retracing the process and progress in scientific knowledge on stratospheric ozone and its depletion reveals some major shifts in the scientific understanding, as well as areas of scientific uncertainties that were not resolved until the early 1990s. From the very beginning, the issue of stratospheric ozone depletion had a speculative dimension. The issue was rather theorized on before it was actually discovered under real-world conditions. The issue popped up as a spill-over from an impact-assessment on SSTs and developed from this origin. It was therefore discovered backwards: Rather than finding an effect and speculating on its source, sources of potential harms were discovered and speculations began what the consequences might be. Since actual ozone depletion was not measurable until the 1990s, different theories and hypotheses were articulated and dismissed. Possible substances that might cause ozone depletion were narrowed down from NO_x and water vapor to chlorine.

The issue has been extensively studied and reviewed by numerous research groups and institutions. While these efforts continuously contributed to a fair understanding of the sources and mechanisms which cause stratospheric ozone depletion, as well as of the consequences for wildlife and humans of increased UV-radiation, the actual extent to which ozone would be depleted under different emission scenarios remained unclear and was not resolved until after political controls had been installed. Quantifying the actual extend to which ozone would be depleted under different emission scenarios was however crucial to balance political steps to effectively protect the stratospheric ozone layer with economic interests. The issue was pragmatically resolved in parallel to negotiations (see section 5.2.4.3).

5.2.4 Stages of Regime Formation

5.2.4.1 Early Efforts Towards Domestic Regulation

The issue of stratospheric ozone depletion entered domestic political debates during the mid-1970s as a result of early ozone research, especially after the publication of Molina and Rowland (1974)'s ozone depletion hypothesis. Countries reacted however differently to the scientific warnings. The U.S. was the world's largest producer and consumer of CFCs, it experienced the strongest SSTs controversy and it was a leading player the research efforts on the stratosphere (Parson, 2003, :42). Therefore, the first political restrictions of CFCs usage were implemented on a state-level. The U.S. passed the first national ban on aerosol usage of CFCs in 1976 (Stoel et al., 1980). In a first step, nonessential use of a specific class of CFCs (CFCs 11 and CFCs 12) was restricted. In a second step, additional CFCs for aerosol use were restricted (Parson, 2003, :40).

Canada regulated the aerosol use in 1976, Germany negotiated voluntary cuts with industries and Sweden banned the manufacture and importation of fluorocarbons in 1977. Australia, France, the Netherlands, United Kingdom, Italy, Japan the Soviet Union and Switzerland had no effective domestic legislation by 1980 (Stoel et al., 1980, :51-71).

5.2.4.2 Early Demands for International Regualtion

Canadian officials and scientists were the first strong proponents of regulations on an international level and lobbied for international action at UNEP and the World Meteorological Organization (WMO). As a result, both organizations initiated calls for internationally coordinated research and policy (Parson, 2003, :44). But despite these efforts, demands for international regulation on CFCs failed throughout the 1970s. Individual opponents brought forward different arguments against international regulation. Japan, for example, simply argued that skin cancer resulting from increased UV-radiation would not effect Asians due to their darker skin (Parson, 2003; Sprinz and Vaahtoranta, 1994). Some governments did not support initiatives for international regulation for domestic political reasons (such as France, Italy and Germany), others (for example the UK and the Soviet Union) strongly opposed the necessity for regulation since scientific evidence did not justify regulatory efforts.

The first action taken by the transnational organizations UNEP and WMO aimed at coordinating research and enhancing knowledge on the issue. Two meetings were hosted by UNEP in 1977 which ended with the conclusion that "participants recognize that the ozone layer is a global resource, and that current knowledge is adequate to give cause for concern about effects of chloroflurocarbon use on the ozone shield. At the same time, there is much to be learned - especially in the effects areas." (Stoel et al., 1980). The WMO restricted its activities to expanding its ozone monitoring group and to issuing regular statements of concern (Parson, 2003, :44). Besides the already mentioned two international bodies, the OECD would have been the probably most fitting platform for international regulation of CFCs. The organization comprised the largest producers and consumers of CFCs (except for the Soviet Union) and had the mandate to initiate multilateral negotiations among member states. Additionally, it had specialized subbodies for environmental issues and chemicals (Parson, 2003, :45). Similar to UNEP and WMO, the first OECD-action aimed at assessing the state of knowledge. After an initiative of Canada and the U.S., the OECD collected scientific findings from its member states and produced a report on ozone depletion and CFC-regulation in 1976. The report confirmed the ozone-depletion hypothesis, but also emphasized the remaining uncertainties and carved out the need for further scientific investigation. Despite further pressure from Canadian and U.S. officials, the OECD remained largely inactive. By that time, "[...]there was no international organization willing and able to coordinate international policy on the ozone issue" (Parson, 2003, :45). Organizations either did not have the mandate or capacity or were blocked by a forceful opposition. Therefore the early international efforts accomplished little. (Parson, 2003, :50)

In the early 1980s, different international organizations initiated action on CFCs with diverse success. The EC-commission's move to cap CFCs-production within the EU failed to accumulate the necessary support. The OECD continued its scientific assessment by conducting model comparisons but was limited by political maneuvers and continuos scientific uncertainties about the actual effect of increased UV-radiation. After these experiences and because of the UNEPs assessment efforts that gained more and more prominence, the OECD discontinued its efforts and shifted to supporting the UNEP's work.

In the light of continuous failure of international bodies to install multilateral policies or initiate at least policy relevant negotiations, proponents of international legislation continued to push for the issue at UNEP. While a Norwegian initiative in 1977 gained little support, it slowly built up and the UNEP Governing Council decided to organize negotiations for an international convention to protect the ozone layer in 1981 (Benedick, 1998). This decision did not imply any intergovernmental negotiations yet, but it allowed UNEP to form a group of technical and legal experts. The group developed the basic structure of the convention as a "treaty and protocols" process. Early drafts and political initiatives that promised a quick negotiating process were rebuffed and opponents pointed to new or uncertain scientific findings that had to be considered before any negotiations (Parson, 2003, :112). Official negotiations started in 1982 without any specific proposals for controls.

5.2.4.3 The Vienna Convention Negotiations and the Montreal Protocol Between 1982-1987

The first negotiation meetings for the Vienna Convention in early 1982 had a rather educational character since many participants were not familiar with the global dimension of the ozone issue. The meeting was set up as an expert meeting, not a negotiating meeting and participants did not arrive at negotiations with clear-cut objectives from their national governments (Morrisette, 1989). However, different drafts and proposals for international regulation were circulated and this meeting already revealed divergent views on what to regulate in what manner and to which quantity. The most prominent proposal was submitted by an alliance of

Nordic countries (the so-called Toronto Group[16]) that called for a ban on nonessential aerosols and technological controls for other CFCs-uses. The discussions that followed circled around this proposal. One obstacle was a lack of knowledge on alternatives to CFCs and the related costs for controls. Some scientific programs refused to address these questions for the sake of scientific credibility, and research groups that addressed the issue did not make much progress (Parson, 2003, :114).

Despite the lack of knowledge and divergent positions, the first session ended with a mandate to UNEP for preparing a draft framework for a convention. The following meetings were marked by the discussion over the initial proposal by the alliance of Nordic countries. Western European countries, Japan and the Soviet Union opposed international controls whereas Canada, Finland, Norway, Sweden and the U.S. supported international regulations (Dimitrov, 2006, :46). While some actors pledged for a refinement of the proposal, other nations objected it as "scientifically indefensible" (Parson, 2003, :115). As negotiations continued between 1984 and 1985, actors more and more underpinned their arguments with new, though ambiguous, scientific findings. While opponents of international regulations emphasized the succeeding decline of predicted ozone loss, advocates pointed to the model of nonlinear ozone depletion. (Parson, 2003, :120). As a result of unresolved conflicts, specific control measures were removed from the convention draft version preceding the meeting in early 1984.

The Vienna Convention was the result of extensive negotiations and was, at most, a compromise between advocates and opponents. In the beginning of the negotiations, the level of general knowledge on the issue was low[17], but during the negotiation process, arguments were repeatedly justified with scientific "facts", regardless of their preliminary character or reliability (Parson, 2003). On the other hand, arguments were repeatedly refused on the basis of alternative scientific models. By signing the Vienna Convention, participating nations committed

[16] Members of the Toronto Group were United States, Canada, Sweden, Norway, and Finland

[17] Some nations even claimed that "their ozone layer" was intact since they were not using CFCs.

themselves to take "appropriate measures" to "protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer". This language reflects the weak character of the convention and the actual effects of the convention on the ozone layer were probably close to none. Nevertheless, the convention produced commitments to future research, exchange of information and - most importantly - future political consideration of the issue. The basic framework of a general umbrella-treaty that is followed by more issue-specific turned out to be helpful in the subsequent negotiation process.

The first negotiation rounds towards the Montreal Protocol experienced similar controversies about the validity of different scientific findings. Especially conflicts over model projections of ozone loss marked the discussions since the projections determined what CFCs-control measures (for example production freeze versus production cut) were necessary to effectively protect the ozone layer and avert harmful UV-radiation. These model uncertainties were however pragmatically resolved during an ad-hoc meeting in a hotel room at Würzburg in 1987 (Skodvin, 2000). At this short-term meeting, modelers standardized and merged different projection models and eventually showed that the biggest source of uncertainty in respect of projection were future CFCs-emission scenarios, thus passing responsibility back to the political arena. Secondly, running a combined model also showed that a simple emission-freeze was insufficient to hold global ozone loss under 2% within the next 50 years. A 2% loss was perceived as an upper threshold to avert serious negative effects (Parson, 2003, :132). The so-called "Würzburg conclusion" posed a turning point in the debates on the scientific basis of a call for regulation. The model results were confirmed at a later meeting of a NASA scientific working group in 1988.

The negotiation rounds that followed were characterized by tactical bargaining maneuvers where actors intended to strengthen their position in order to influence the outcome of negotiations to their favor. As negotiations continued in 1987, several remaining differences were narrowed or resolved (Parson, 2003, :136). Exceptions were negotiated for CFC-uses that could still not be substituted (such as some medical applications) and timelines for meeting the targets of the Protocol were exceptionally extended for developing countries. As a result, nations merely needed to clarify technical issues of the Protocol. (Parson, 2003, :133).

5.2.5 Costs, Benefits and Uncertainties of CFCs-Regulation

While the previous sections offer an across-time analysis of the process of both the scientific as well as the political developments, this chapter aims at testing the argument against operationalized indicators for costs and benefits. This offers a deeper understanding on the profile of negotiating countries and allows to conclude about changes within the configurations through either changes in behavioral patterns or changes in scientific knwoledge. Chapter 4 provided the rationale for operationalizing *costs* as direct costs from international regulation and *benefits* as reduced vulnerability. Costs from international regulation are (in line with (Sprinz and Vaahtoranta, 1994)) operationalized as CFCs-consumption in relation to GDP per capita. This follows the logic that international regulation would imply emission cuts which would cause economic costs, since more cost-intensive substitutes have to be developed or certain products would not be available to the market anymore.

Benefits – or reduced vulnerability – are conceptualized as the amount of estimated ozone loss. While Sprinz and Vaahtoranta (1994) suggest to operationalize benefits as a function of skin-cancer, rates of ozone loss are more suitable to capture the whole spectrum of negative effects and represent vulnerability at an earlier point in the causal chain from CFCs-emissions to vulnerability. Therefore, vulnerability is conceptualized as rate of predicted ozone-loss in per cent. As figure 5.1 shows, predictions on how much ozone would be lost in the future varied significantly across time and between scientific institutions. For the purpose of this study, the years 1978 and 1984 have been selected for a cross-time comparison for several reasons. First of all, the beginning and the end of the interval both preceded international regulation. At the beginning of the interval in 1978, concerns on ozone-loss had already been raised and early political maneuvers was observable at the international

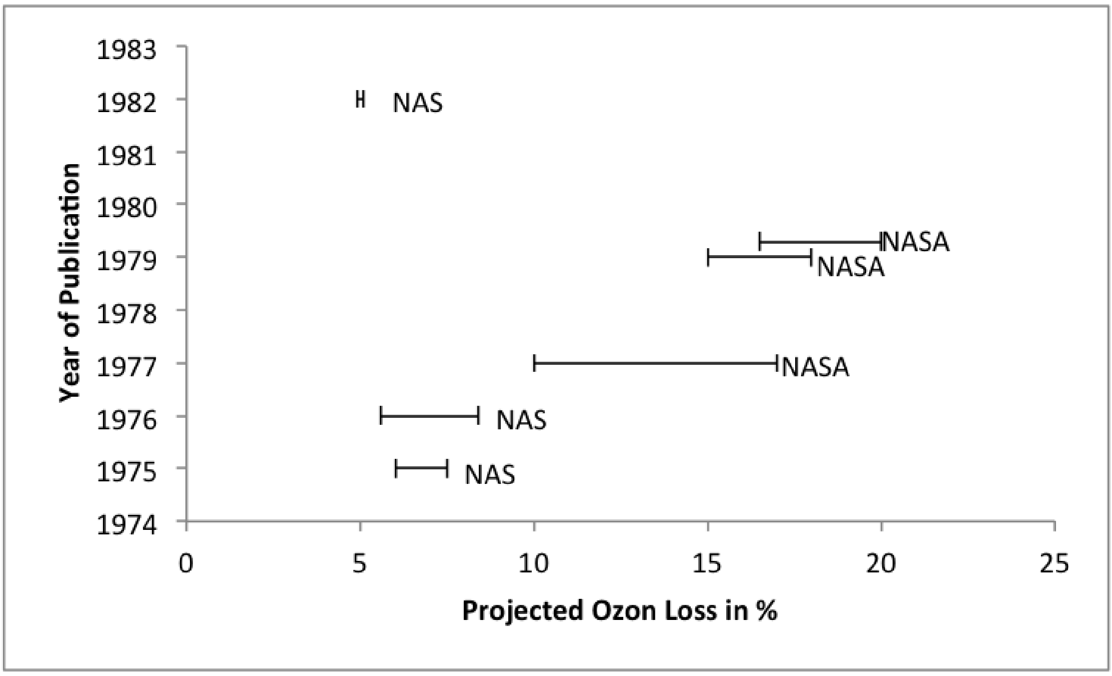


FIGURE 5.1: Ozone Projections by the National Academy of Science (NAS) and the National Aeronautics and Space Administration (NASA) between 1975 and 1982

level. The interval ends shortly before international negotiations on the Vienna Convention were closed. Since at both points, states have already somehow engaged in the ozone issue and participated in knowledge-exchange (for example at early meetings for the Vienna Convention), the state of scientific knowledge that was communicated through the official assessment work of the National Academy of Science can be assumed to be commonly shared among participants. Secondly, data prior to the international agreements on CFC-consumption is available only for those two years.

The data shows two trends: the first implication is that – despite missing data of some countries – CFC-consumption declined in some countries while other countries increased their consumption. Secondly, it seems as if ozone loss as well as the uncertainty concerning ozone loss predictions declined. However, data on ozone loss has to be interpreted with caution. First of all, data for both listed years are model-based predictions. Between 1976 and 1987, various institutions had published different mode-based predictions of ozone loss that showed strong variance between and within models (see figure 5.1). With the experience of these

Country	**CFC-Consumption in 1978** [a]	**CFC-Consumption in 1986** [b]	**Projected Ozone Loss 1979 in percent** [c]	**Projected Ozone Loss 1984 in percent** [d]
Australia	1.45	1.1	16-20	3
Canada	2.0	1.5	16-20	3
Denmark	n/a	0.3	16-20	3
Finland	n/a	0.3	16-20	3
France	3.6	3.7	16-20	3
Germany	5.2	3.6	16-20	3
Italy	5.5	4.7	16-20	3
Japan	3.4	4.5	16-20	3
Netherlands	1,0	n/a	16-20	3
Norway	n/a	0,8	16-20	3
Soviet Union	9,6	28.5	16-20	3
Sweden	0.3	0.3	16-20	3
Switzerland	n/a	0.3	16-20	3
UK	0.49	4.5	16-20	3
USA	28,6	11.3	16-20	3

[a] in relation to GDP/capita (metric ton / US$). Source for CFC-Data: Stoel et al. (1977):15. Source for GDP-Data: World Bank.
[b] in relation to GDP/capita (metric ton / US$). Source for CFC-Data: McCulloch et al. (1994):348-349. Source for GDP per capita: World Bank.
[c] Source: NRC (1979a)
[d] Source: NRC (1984)

Table 5.11: CFC-Consumption and Ozone Loss Predictions between 1978 and 1986

strong fluctuations in mind, there were strong reasons to question the reliability of the predicted ozone loss. Both NASA and the WMO declared in 1986 that actual ozone levels would probably deviate between 20-30% from model predictions (Dimitrov, 2006).

5.2.6 Conclusions

The scientific and political recognition of stratospheric ozone loss evolved in different stages of activities, advancements and dead-locks. Research on stratospheric ozone loss began in the 1960s, but the primary cause for anthropogenic ozone depletion was not found until the mid 1970s. And even by then, the scientific basis was rather slim, leaving room for speculations and contradicting hypotheses. Knowledge consolidated over the years and the qualitative link between CFCs-emissions and ozone loss gained consensual recognition. However, quantifying the exact loss of stratospheric ozone to current and future CFCs-emissions as well as deciding which levels of ozone loss could be tolerated as acceptable remained extremely difficult.

In the 1960s, the substances Cl, NO_x and water vapor were suspected to catalyze stratospheric ozone. The only possible pathway through which these substances could enter the stratosphere were assumed to be Supersonic Transporters which were not even in place by that time and it was unclear if they ever would be manufactured. After Molina and Rowland (1974)'s early speculation on stratospheric ozone destruction, direct economic costs as well as actual levels of vulnerability remained unclear. Their hypothesis merely *suggested* a link between CFCs-emissions and stratospheric ozone destruction. Additionally, research on possible substitutes was for most applications still at its infancy and countries could not project the economic effects of broad and universal regulation on CFCs-emissions.

Molina and Rowland (1974)'s hypothesis gained however more and more recognition and it became a consensus that a qualitative link between CFCs-emission existed, though it remained unclear to what extent ozone would be lost and what thresholds would be acceptable. The formulation Vienna Convention can be regarded as a reaction to the scientific picture of that time and fits the predictions of the theoretical argument in chapter 3. Through the Convention, states confirmed the existence of anthropogenic ozone depletion and stated that the global ozone layer should be preserved. The process of negotiations, the vague language and the call for additional research on the issue indicates that the knowledge at hand did not (yet) call for immediate political action.

The continuing political process towards international protection of the ozone layer was marked by disputes over scientific findings and differences between models, especially with regard to project future ozone depletion. Two major shifts in the scientific perception evolved during that period of time: the Würzburg conclusion and industry announcements on the technical feasibility of potential alternatives. Both shifts did not feed new scientific findings into the political process. Knowledge on the technical feasibility of potential substitutes had been developed in the late 1970s (though knowledge was not advanced enough to develop products that could compete with CFCs on every level), but it did not find political recognition. When the same research results were republished in 1986, it drew the attention of political actors. The Würzburg conclusion represents rather a pragmatical choice of how to overcome model uncertainties than new findings on future ozone loss. But even though both aspect were not entirely new, they gained political recognition for the first time. Table 5.12 provides an overview on scientific and political events on stratospheric ozone protection, as well as the cost-benefit-configurations as they were developed in chapter 3.

The two scientific shifts mentioned – the Würzburg conclusions and findings on cost-efficient substitutes – changed the configuration of costs and benefits into a more conducive profile which made a regime formation process more likely. However, while the two scientific shifts reduced scientific uncertainty from the perspective of states, it did not rule out dissimilarity. As Barrett (2001) and others convincingly show, sovereign states cannot be forced into a multilateral environmental agreement and have therefore to be similar (or 'symmetrical) in their configuration of costs and benefits. As a look at data on consumption and human health

	1960 - 1973	*1974-1985*	*After 1985*
Scientific Process	Theory on four substances from SSTs exhausts with potential to destroy ozone: NO_x, Cl, HCl, and water vapor. Findings on high atmospheric CFCs concentration by Lovelock et al. (1973). Sporadically published concerns about negative effects from ozone loss. No data on the extent of ozone loss.	Lovelock (1974) formulates hypothesis on CFC-emissions and ozone-loss. (Molina and Rowland, 1974) confirm and refine hypothesis. Several scientific findings support hypothesis. First estimates on negative consequences from ozone loss in official assessment work. Varying model-based estimates on the extent of ozone loss in official assessment work.	Confirmation of CFC-hypothesis. Confirmation of hypothesis on ozone-loss and skin-cancer. Pragmatic consensus that ozone-loss would exceed the 2% threshold despite a production freeze. Findings on cost-efficient alternatives.
Cost-Benefit Configuration	Uncertain costs, uncertain benefits.	Low costs, uncertain benefits for aerosol uses; high costs, uncertain benefits for non-aerosol uses.	Low costs, high benefits for both aerosol- and non-aerosol uses.
Expected Political Reaction	No political effort to regulate CFC-emissions (diplomatic efforts to terminate SSTs by most vulnerable countries). Intensification of research activity, international coordination of research activities.	Acknowledgement of ozone-depletion as an international issue. International regulation for aerosol uses, no regulation of aerosol uses.	International regulation for all uses.
Political Process	Domestic regulation on the use of CFCs (especially aerosol use) in some Countries. National assessment programs through NASA, NAS.	Coordination of research through international agencies like UNEP, WMO and OECD. Clarification on the scientific dimension during negotiations towards the Vienna Convention in 1985. Commitment to further political action and coordination of scientific research.	Montreal Protocol 1987: Legally binding multilateral agreement on a ten-year phase-out of production and consumption of CFCs.

TABLE 5.12: Milestones in Scientific Research and Political Action on CFCs

effects from increased ultraviolet radiation shows (Sprinz and Vaahtoranta, 1994), this was certainly not the case. The agreement was actually achieved through a political compromise between supporters of a 95% cut and supporters of a phase out (Parson, 2003).

The case of stratospheric ozone protection allows to test the theoretical argument and the hypotheses in different ways. The historical process tracing shows how scientific knowledge shifted and how the political process reacted to these shifts. At a first glance, the hypotheses are supported: by the time the ozone issue was discovered, scientific uncertainty was high on both dimensions (costs and benefits) and political action was directed at improving knowledge. As it became clear that regulating aerosol uses could be easily achieved, many states installed domestic regulation on aerosol use. At the same time, international efforts to regulate non-aerosol uses failed. This changed when new scientific findings revealed a more conducive cost-structure for substitutes and when scientific knowledge confirmed high vulnerabilities.

Even though this simple explanation for the success of regime formation is appealingly convenient, some aspects do not fit and alternative explanations have to be considered. For example, shifts in scientific knowledge cannot explain differences in domestic regulation that preceded international regulative efforts. Especially early regulation in the U.S. (by that time one of the biggest consumers of CFCs) did not follow shifts in scientific knowledge. However, strong public attention, pushed by NGOs, had already changed markets for aerosol uses of CFCs (Parson, 2003, :59), which softened industry opposition and facilitated domestic regulation within the U.S. Many other industrial nations followed and introduced different forms of domestic restrictions upon aerosol CFC-use (Stoel et al., 1977). It can be argued that preceding domestic regulation – though weaker and exclusively focused on aerosol uses of CFCs – paved the way for international restriction.

Secondly, shifts in scientific knowledge do no necessarily resolve dissimilarities between countries. It has been argued that new scientific knowledge about the extent of ozone loss and substitutes for non-aerosol uses reduced the scientific uncertainties to a degree where states could expect that their costs from international regulation would be low while benefits were high, since ozone loss appeared to be greater than expected. This, however, did not resolve distributional conflicts that would arise from international regulation.

Most interestingly, the study shows how the scientific debate can be shaped by actors. The Würzburg conclusions were a conscious decision by actors to deliberately emphasize some aspects of science and ignore some other aspects of knowledge to deliver a clear-cut result as the basis for policy decisions. In this case, it can hardly be argued that scholars manipulated scientific knowledge in a particular direction to foster their individual interests. The occasion however shows that "scientific results" are not necessarily the results of pure scientific research. Therefore, the interaction between science and interests could go in both directions. Though no research on the case of stratospheric ozone protection hints in this direction, it certainly is an agenda for future research to further understand the relationship between scientific knowledge and political interests.

5.3 The Non-Regime on Arctic Haze

> "For a while, it looked so simple: greenhouse gases warm the Earth and sulphate aerosols cool it down. [. . .] But this simplistic view ignores the fact that aerosol particles in the real world are not white but grey, mostly because they contain soot particles from the incomplete combustion of fuels."
>
> Meinrat O. Andreae *The dark side of aerosols*

Despite its early scientific recognition, Arctic haze has produced a rather fragile and contradictory body of research. Moreover, even though the issue has been debated at high-level political institutions, it has not caused too much political reaction. The case is especially interesting, because the scientific process is marked by big shifts. As the study will show, scientific uncertainty leads to the paradox effect that policy makers do not know whether political action would avert or, on the contrary, even enhance the undesired consequences from Arctic haze. It is therefore not clear whether Arctic haze should be avoided or not. The case is very suitable to test the argument, as scientific knowledge is uncertain to a degree that does not allow actors to formulate their own costs and benefits.

Arctic haze is a layer of brownish mist that covers the Arctic at an altitude of 10-20 km, covering roughly the region north of the 66th parallel on the northern hemisphere. Oral tradition of the native Inuit suggests that the phenomenon set in with the industrial revolution and even Fritjof Nansen – one of the earliest explorers of the Arctic – was puzzled by residues of black dust on Arctic snow (Soroos, 1992). The first scientific description was published in *Science* in 1883 (Nordenskiöld, 1883). However, the phenomenon did not raise too much attention until the 1950s when pilots crossing the Arctic reported a brownish fog of unknown origin that occurred during winter and spring (Greenaway, 1950). According to Mitchell (1957), who coined the term 'Arctic haze' but did not think of it as air pollution, pilots described the haze as hundreds to thousand kilometers wide and 1-3 km thick. It occurs in diffuse layers in the lower troposphere (at approximately 15 km altitude) and consists of sulphate particulate organic matter (POM) ammonium, nitrate, dust, and black carbon (Li et al., 1993) of mostly anthropogenic origin (Rahn, 1981). Arctic haze is a highly seasonal phenomenon with peak concentrations during early spring and very low concentrations during the summer (Shaw, 1995). Moreover, Arctic haze has been traced back to sources in Eurasia and North America and it is suspected to disturb the highly sensitive regional Arctic climate system (Rinke et al., 2004). The significance of the Arctic climate for the global climate system has been emphasized by many scholars of climate change (IPCC, 2007b).

Despite the significance of the local Arctic climate for the global climate, Arctic haze has received little political attention, neither on a national nor on a multilateral level. So far, no international regime has been created to address the issue of Arctic haze. Weak political, non-binding commitments to protect the Arctic environment have been formulated in 1989 in the 'Declaration On The Protection Of The Arctic Environment' ('Rovaniemi-Declaration'), which was signed by Canada, Denmark, Finland, Iceland, Norway, Sweden, the USSR and the USA. Through the declaration, states committed to initiate an assessment process on environmental and economic conditions in the Arctic and established the 'Arctic Monitoring and Assessment Programme' (AMAP). The signatory states formed the 'Arctic Council' in 1996 as a weakly institutionalized forum to discuss issues on sustainable development which comprise environmental and socio-economic issues of the Arctic region (Bloom, 1999). The forum aims at coordinating cooperation on various aspects of the Arctic region, such as socio-ecomomic issues of indigenous people, fishery or environmental issues. Even though AMAP repeatedly presented the issue of Arctic haze to the Arctic Council, where it was discussed in numerous official meetings, and despite calls for multilateral action by some participants within the Arctic Council framework, no legal action was taken to address the issue.

5.3.1 Defining Costs, Benefits and Uncertainty of Arctic Haze

Arctic Haze has been identified as a potential problem because of its high concentration of sulfur and the high proportion of black carbon. High sulfur concentration and other acidifying chemicals might threaten the fragile biological equilibrium of the Arctic flora and fauna. The issue of acidification, however, is geographically limited to the Arctic region and might be of little interest for states that do not have stakes in a healthy Arctic eco-system. The high proportion of black carbon in Arctic haze, however, poses a more transregional, transboundary problem. Black carbon is a short-lived climate forcer in the Arctic and some researchers argue that it is the second most important driver for global climate change after CO_2 (Ramanathan and Carmichael, 2008). However, despite substantial scientific improvements, the role of particles in clouds and the Arctic is not very well understood so far. This case-study will focus on black carbon for two reasons: First of all, sulfur and and other acidifying chemicals have already been regulated by the CLRTAP (see section 5.1) to which all Arctic nations are members. Measurements show that their proportion in the composition of Arctic haze has progressively declined (AMAP, 2006). Secondly, acidification affects predominantly the Arctic region itself with fewer negative effects for other areas and lacks a transboundary dimension. Thirdly, the effects of anthropogenic sulfur in the environment have been studied in depth and few scientific blank spots are left here.

Black carbon in the Arctic, on the other hand, has the potential to accelerate global climate change, and thus has a more transboundary character than sulfur-acidification. The climatic effects of black carbon mitigation are more direct than those of other climate change drivers such as CO_2 or methane. It is not a greenhouse gas, it rather soots out and darkens the large snow-fields of the Arctic and Antarctic and, as consequence, diminishes surface albedo. A decreased surface albedo through darkened surface results in more sunlight to be absorbed by the surface. This, in turn, might lead to a warmer Arctic surface climate and an enhanced melting of Arctic ice shield (IPCC, 2007c). This could eventually rapidly speed up the process of climate change through a variety of mechanisms and complex feedbacks.

As already emphasized, there is no multilateral agreement on Arctic haze despite political efforts in this direction. Since the issue was already found to be characterized by scientific uncertainty (see 4.3.1) and there is no international regime, we would expect, in line with the argument, an obstructive configuration of scientific uncertainty in which costs of mitigation are uncertain while benefits from international regulation are rather low (see section 3).

Since black carbon has been identified as the central transboundary issue of Arctic haze, the economic costs of a multilateral Arctic haze agreement are represented by domestic emissions of black carbon. The higher annual black carbon emissions per capita, the higher potential costs from regulating or cutting these emissions. According to the theoretical argument, we would expect that emissions are rather uncertain since they are hard to measure.

Benefits from an international agreement on Arctic haze are conceptualized as reduced vulnerability. In contrast to the previously described phenomenon of Persistent Organic Pollutants, vulnerability to black carbon occurs as an indirect effect and in relation to its role as climate forcer and its potential to significantly enhance climate change. Therefore, vulnerability from Arctic haze is reflected by vulnerability towards dramatic climate change. In line with the theoretical argument, we would expect that the Arctic council states are experiencing a rather low climate change vulnerability.

5.3.2 Outline of the Case Study

The case study will geographically focus on the members of the Arctic Council. At the same time, research indicates that these are the main emitters of black carbon that travels to the Arctic and on the other hand Arctic haze has been addressed as a political issue within that organization (Soroos, 1992).

To ensure comparability, this case study follows procedure similar to that of the previous case study. *Nature* and *Science* are scanned for publications on Arctic haze. Two additional relevant scientific journals are identified through the references of the articles in *Nautre* and *Science*. The journals have been scanned for the key-words *Arctic Haze, black carbon, Arctic air pollution* and *short-lived climate forcers*, as well as a combination of these terms. Additionally, the scientific journals *Journal of the Atmospheric Science* and *Journal of Geophysical Research* have been analyzed for publications on Arctic haze and black carbon in the Arctic. The review led to a data-set of 46 articles, which were scanned for research themes and existing scientific uncertainty. The themes that dominated the scientific debate were *sources, composition, long-range transport* and *effects* related to Arctic haze. For an overview on the reviewed articles, see the appendix.

Similar to the previous case studies, data collection has been supplemented by a citation analysis using 'CiteSpace', with the search terms 'Arctic haze' and 'black carbon emission'. The following case study rests on insights from a qualitative content analysis (Mayring, 2010) of the collected data.

5.3.3 Historical Stages of Scientific Knowledge on Arctic Haze

5.3.3.1 Origins and Sources of Arctic Haze

For the Inuit population, the origin of the new phenomenon was to a large extent unknown and interpreted religiously. To early western explorers and the first pilots who noticed Arctic haze in the 1950s, its origin seemed puzzling as well, especially since the Arctic was thought to be a remote and pristine area. There was, however, little scientific interest on where the haze came from and how it got to the Arctic. This changed when Glenn E. Shaw started to investigate optical depth at Barrow, Alaska (Shaw, 1975). Optical depth measurement (or optical thickness measurement) is a simple method to determine the amount of particles in the air by means of light scattering. He intended to collect clean template samples in the Arctic as baseline levels for polluted urban areas and was puzzled when he found optical depth to be much deeper than he expected, indicating much higher particle concentration in the air than theory and previous research suggested (Shaw, 1989). Nearby sources could quickly be excluded as causes and rough trajectory analysis hinted to an anthropogenic origin from northern America. However, this assumption was refuted by Rahn et al. (1977), who identified the origins in the Asian deserts. At the time, two models to explain a longer-than-usual atmospheric life-time and a longer-than-usual travel route for aerosols were available: either aerosols were induced through volcanic erruptions (Crutzen, 2006) or windblown from deserts (Shaw and Stamnes, 1980; Sinclair, 1974). Since a volcanic origin could be excluded and the timing matched with seasonal sandstorms in Asian deserts, Rahn et al. (1977) assumed that the particles originated from Asian deserts and published these assumption in *Nature*. Since the composition of Arctic haze was similar to Sahara aerosol and long-range flow patterns of aerosols supported the assumptions, scholars agreed that Arctic haze consisted mainly of wind-blown dust from Asian deserts (Barrie, 1986).

Further research in the early 1980s, however, gave reason to doubt the suggested explanation of wind-blown dust (Rahn and McCaffrey, 1980; Rosen et al., 1981). By the late 1970s, data was still incomplete and scattered and the sources of Arctic haze had not been clearly identified, but evidence suggested to rule out some suspected sources: "Haze is not correlated with or chemically similar to several sources of air pollution on the north slope of the globe"(Shaw, 1989, :73). This excluded any local sources for the haze. Since local sources and asian deserts seemed implausible sources for Arctic haze, researchers speculated that industrial sources from central Eurasia and northern America could contribute to Arctic haze (Shaw, 1989, :73). By that time, scientific knowledge left no doubt that Arctic haze was an anthropogenic phenomenon of remote origin. This seemed surprising since scientific theories indeed showed how particles traveled through air currents, but by far not over such a long distance.

A new publication of Rahn and Heidam (1981) initiated a major shift in the understanding of Arctic air pollution and long-range atmospheric transport of particles.

Their research demonstrated why previous assumptions on Artic haze sources in Asian deserts *must* be mistaken and suggested that industrial sources in central Eurasia, eastern Europe, and northern America were major contributors (Rahn and Heidam, 1981, :1448ff). The analysis of particle composition allowed Rahn and Heidam (1981) to infer Eurasia as the main contributor with North America to a lesser extent. Rahn and Heidam (1981), however, emphasize that the assumptions rest on a patchwork of several publications on Arctic haze and significant knowledge gaps and lacks in data still prevailed. Further research by Barrie et al. (1981) partly supported Rahn and Heidam (1981)'s assumption, but ruled out European sources (Barrie et al., 1981, :1415) and identified additional possible sources, such as Japan and Siberia. Research continued and particles were furthermore analyzed, using x-ray spectrometry to trace back their origin. The results published in *Nature* support once more the idea of Eurasian and North-American sources as contributors to Arctic haze (Shaw, 1982)[18]. A growing body of research research, using new emerging methods, supported the hypothesis of Eurasian and North-American sources (Rahn and Lowenthal, 1984). By the early 1990s, the hypothesis of sources from Eurasia and North-America had become scientifically accepted and confirmed by additional research that combined chemical analysis with meteorological findings on the transport of aerosols (Cheng et al., 1993; Nriagu et al., 1991)(see also section 5.3.3.2) and the research focus shifted towards more detailed questions of transport mechanisms, composition and environmental effects (Djupström et al., 1993).

5.3.3.2 Transport and Long – Range Migration

Research on aerosol transport is closely linked to research on sources and many publications address both aspects. The puzzling discovery of Arctic haze by Shaw (1975) had already raised questions about transport patterns. The standard model for aerosol migration in the 1970s suggested wind-blown dust over a few hundred

[18] Shaw (1982) corrected his own previous research which suggested Asian deserts as sources. He called this early *Nature*-article his 'Red Herring Paper' (see: http://gi.alaska.edu/glenn/research/Arctichaze)

kilometers. However, when researchers found that the composition of Arctic haze pointed to sources around 1,000-3,000 km away, the focus shifted towards unique features of Arctic climatic conditions (Barry and Hare, 1974; Kerr, 1979). Rahn and McCaffrey (1980) developed the first crude model of the meteorological interaction between the local Arctic climate system and mid latitude climate system. Since many studies implicated strong variations of Arctic haze density between winter (strong concentration of Arctic haze) and summer (low concentration of Arctic haze) and a quite sudden change between seasons, Rahn and McCaffrey (1980) assumed an influence of seasonal temperature difference and developed the model of 'coupling-decoupling'. Put simply, it describes how both systems couple in winter, allowing large air massess to travel into the Arctic and decouple in summer, separated by the Arctic front, a weather front between cold Arctic air massess and warmer polar air massess. The rough model was refined by Raatz and Shaw (1984), who investigated in detail the interaction between low-pressure and high-pressure systems in the northern hemisphere. Especially the interaction between a seasonal low-pressure system over Iceland and a constant Arctic high-pressure system allowed researchers to identify nine different pathways from North-America and Eurasia to the Arctic, seasonal deviations of long-range pathways, as well as vertical deviations (Raatz and Shaw, 1984, :1504). The model corresponded with theories on 'blocking' (Austin, 1980; Iversen and Joranger, 1985) and was confirmed by airplane and ground measurements (Bridgman et al., 1989; Burkow and Kallenborn, 2000; Carlson, 1981; Mackay and Wania, 1995; Ottar, 1981; Ottar et al., 1986; Rosen and Hansen, 1985; Shaw, 1989). Since additional research on pathways and long-range particle transportation confirmed model predictions, the model had become the standard model by the early 1990s and was integrated into the first AMAP Assessment Report to explain Arctic air pollution (Wilson et al., 1998, :22).

5.3.3.3 Composition of Arctic Haze

Neither the members of early Arctic expeditions nor the pilots in the 1950s had any knowledge about the composition of Arctic haze. The rather unscientific term

'Arctic haze' itself reflects this lack of knowledge. However, after its rediscovery in the 1970s, much research was devoted to decoding the composition of Arctic haze (Winchester et al., 1985). After falsely assuming natural sources of Arctic haze, namely extraordinary weather events during the time period of measurement (Shaw, 1989, :88), early trajectory studies discovered that Arctic haze contained natural, as well as anthropogenic elements. Tracing anthropogenic elements had proven to be difficult at that time since (a) anthropogenic aerosols could not easily be separated from natural aerosols and (b) the Arctic climate with low temperatures and high seasonal variation in solar radiation causes complicated chemical reactions (Shaw, 1989) that bias measurements. By the late 1970s, the main pollution substances had not been understood (Rahn and Heidam, 1981, :1345). Research focused on tracers to investigate sources and pathways. However, tracers as Vanadium (V) play only a very minor role in the total composition of Arctic haze (Rahn and Heidam, 1981; Rahn and McCaffrey, 1980). Sulfuric acid (SO_4^{2-}) was identified as a constituent, but neither its fraction of the total aerosol mass nor the particle-size distribution was known. Additionally, "graphitic carbon" (Rahn and Heidam, 1981, :1346) was discovered as a fraction of Arctic haze. At issue-specific scientific conferences, Arctic chemistry was still described as being in its infancy (Rahn and Heidam, 1981).

The level of understanding improved with methodological advances in the late 1980s when researchers found a whole spectrum of different chemicals (Heintzenberg et al., 1981). Among the anthropogenic elements, those with the highest occurrence were found to be vanadium (V), sulfuric acid (SO_4^{2-}), nitrate (NO_3^-), black carbon and smaller amounts of other elements which are typical byproducts of industrial combustion processes (such as iron (Fe), magnesium (Mg) and copper (Cu) (Heidam, 1984; Parungo et al., 1990; Rosen et al., 1981; Shaw, 1989; Sheridan and Musselman, 1985; Sheridan and Zoller, 1989). However, even with improved methods, it remained difficult to separate natural from anthropological sources and to exclude measurement artifacts. This led to false artifactual speculations on anthropogenic concentrations of bromine (Br) (Shaw, 1989, :89), which were later corrected (Barrie et al., 1988).

By the early 1990s, airplane measurements, executed during the Arctic Gas and Aerosol Sampling Program (AGASP), had provided detailed data on on the composition of Arctic haze in the stratosphere and troposphere (Davidson et al., 1993; Parungo et al., 1990). The new data provided insights into the relative concentration of different elements within Arctic haze. It revealed that previous ground-based measurements underestimate the fraction of black carbon that is present in Arctic haze (Hansen and Novakov, 1989). The results of the extensive AGASP-measurements were included into the first AMAP Assessment Report: “Haze aerosols are mainly sulfate. The haze has been thoroughly analyzed. It consists of sulfate (up to 90 percent), soot, and sometimes dust. The particles are about the same size as the wavelength of visible light, which explains why the haze is so apparent to the naked eye.” (Wilson et al., 1998, :135).

5.3.3.4 Local and Global Effects of Arctic Haze

Arctic haze has been associated with at least two possible effects on the Arctic. As it became clear that Arctic haze consisted to a large extent of SO_4^{2-} and previous experiences in the Scandinavian environment showed how SO_4^{2-} had a decreasing effects on the ph-level of soils and lake water (which, in turn, threatened local flora and fauna) (Likens et al., 1972; Schindler, 1988), researchers had started to speculate on possible negative effects of SO_4^{2-} in the Arctic (Barrie et al., 1981; Kerr, 1979). However, by the late 1970s, only very little was known about the nature and quantity of any such effects and nothing at all was known on possible sinks[19] for Arctic haze.

Besides concerns about changes in the Arctic environment due to increased SO_4^{2-} levels, scholars had started to theorize on thermal effects from black carbon within Arctic haze. Because of its special characteristics, the Arctic region was thought to be very sensitive to thermal changes. The high reflectiveness (also called ‘albedo’) of a white surface which is covered with ice and snow for the most of the year, coupled with long periods of constant sunlight (Arctic summer) or vice versa long

[19] In ecological science, a ‘sink’ is broadly described as a physical place or area where material collects and accumulates.

periods of darkness (Arctic winter) leads to a fragile equilibrium of temperature, precipitation patterns and wind currents. And since thermal impacts from air pollution were known from other regions (Warren and Wiscombe, 1980), scholars began to hypothesize on possible effects.

Shaw and Stamnes (1980) developed the first model on how Arctic haze might influence the polar radiation budget[20]. The model has made it possible to identify two mechanisms resulting in different effects in the atmosphere and on the surface. Arctic haze (a) decreases the albedo of atmospheric clouds, thus absorbs solar radiation in the atmosphere which also (b) shields the surface from solar radiation. According to the model of Shaw and Stamnes (1980), the albedo effect of Arctic haze leads to increasing temperatures in atmosphere[21]. Solar radiation absorption leads to an oppositional effect: Solar radiation is prevent to hitting the surface, thus Arctic haze works like a parasol or sunshade.[22]

Even though the model estimates a temperature increase of 1° C per day in the lower troposphere, Shaw and Stamnes (1980) assert a net cooling effect from Arctic haze, meaning that the shading-effect outbalances the atmospheric heating effect. Other modeling-approaches on black carbon in the Arctic atmosphere confirmed in principle Shaw and Stamnes (1980)'s conclusion (Cess, 1983; Porch and MacCracken, 1982; Rosen et al., 1981; Tsay et al., 1989), but corrected the magnitudes of estimated atmospheric temperature increase to be much lower (Leighton, 1983). However, as Cess (1983) points out, all of those models suffered from questionable assumptions and a lack of data. "The parameters that would have to go into the models are, however, known only poorly." (Shaw and Stamnes, 1980, :537). Furthermore, the models only pictured temperature effects within Arctic haze layers and did not link this effect to dynamic feed-back processes (Barrie, 1986). A general increase of local atmospheric temperatures has nevertheless been regarded as established scientific knowledge in the early 1980s, but its magnitude and further

[20]A local or regional radiation budget refers to the balance between incoming solar radiation and outgoing albedo-radiation (reflected radiation by the local or regional surface).

[21]The effect of light absorbing black carbon particles is comparable to wearing a black shirt in the summer sun.

[22]This effect is even enhanced by SO_4^{2-} in Arctic haze.

implications could only be guessed (Rahn and Heidam, 1981). Estimations on radiative effects improved as data from ground measurements was supplemented by airborne-sample data (Patterson et al., 1982; Wendling et al., 1985) and supported the initial assumption of increasing temperatures in the lower troposphere, a cooling surface and a net cooling effect from Arctic haze.

While models on the effect of aerosols in the Arctic troposphere gradually improved, the deposition on snow and its effects on Arctic climate particles remained puzzling during the 1980s (Rahn, 1985). Research on long-range transport indicated a movement from mid-latitudes to the Arctic, but only little was known on the fate of the particles (Rahn and Heidam, 1981). The standard paradigm was that deposition of particles must be very small in the Arctic (Shaw, 1989), since climatic conditions were assumed to be rather stable. This view changed during the mid-1980s when more research effort was dedicated to mechanisms and concentrations of Arctic haze deposition. Between 1985 and 1990, studies reported residues of SO_4^{2-} (Davidson et al., 1987) and black carbon in Arctic snow-packs (Blanchet, 1989; Clarke and Noone, 1985; Noone and Clarke, 1988). Basic mechanisms of deposition were identified, but quantifying deposition to assess environmental impacts was not feasible (Shaw, 1989). Measurements showed an acidifying effect of SO_4^{2-} on snow surface, but it was black carbon raised most attention since it has the potential to increase surface temperatures and might lead to increased snow-melt (Hansen and Novakov, 1989). Previous models had focused on temperature changes within the haze layers and close to the surface and neglected the effect of light-absorbing particles on snow (Blanchet, 1989). Additionally, previous research had indicated that the Arctic climate is highly sensitive to slight changes in temperatures as well as to the timing of certain climatic events such as the spring snow-melt.

Despite reasonable concerns that black carbon did not only decreases cloud albedo but also decreases surface albedo by darkening the snow-white surface, research in the 1990s mainly focused on the effects of atmospheric black carbon. Despite possible regional and global climatic impacts (Menon et al., 2002; Ramanathan et al., 2001), changes in surface albedo and resulting effects were largely neglected.

This is reflected in the first AMAP assessment report in 1998, in which SO_4^{2-} was considered to be the main problematic issue of Arctic haze (Wilson et al., 1998). While some publications had already pointed out possible climatic effects of decreased surface albedo (Menon et al., 2002; Ramanathan et al., 2001), , the scientific community on global climate change did not take it into consideration (Houghton et al., 2001).

Albedo decreasing black carbon gained prominence after 2000. Jacobson (2001)'s Article in *Nature* emphasizes (a) how the radiative forcing of black carbon strongly depends on mixtures with other aerosols, (b) has been widely underestimated by previous research and (c) is very hard to quantify with certainty. But based on his model results, he suggests that black carbon might easily offset the cooling effect of other anthropogenic aerosols and might thus be the second most important driver of global warming after CO_2 in terms of direct forcing (Jacobson, 2001, :695). This view is however put into perspective by Andreae (2001), who points out that, although Jacobson (2001)'s work is based on " ... best current knowledge or assumptions" (Andreae, 2001, :671), the actual role of black carbon is still difficult to determine. In a publication in *Nature*, Andreae (2001) summarizes how the effect and the direction of signs of the effect (a) strongly depends on various parameters (e.g. location, latitude, altitude, timing and size of black carbon occurences) and (b) how modelers and experimentalists struggle to determine both magnitude and sign of a possible climatic effect from black carbon.

New modeling results of Hansen and Nazarenko (2004) were published in a highly cited PNAS publication. They integrate climatic forcing of black carbon on snow into climate models and their calculations suggest a substantial increase in radiative forcing (up to 0.16 W/m^2) in the Arctic. The authors inferred that black carbon in the Arctic can account for one quarter of observed global warning (Hansen and Nazarenko, 2004, :428). This changing knowledge about the role of black carbon is also reflected by the fourth AMAP assessment report[23] from 2006, which devotes a section to possible climatic effects from Arctic haze. It summarizes scientific knowledge on the effects of Arctic haze and concludes that (a) atmospheric

[23] The second and third assessment report does not address Arctic haze

black carbon heats up the haze layers, (b) black carbon on the surface reduces albedo and therefore might be a climate forcer and (c) magnitude and sign of radiative forcing for the Arctic are not well understood (AMAP, 2006, :40). Deposition and fluctuation in concentrations remained a great source of uncertainty (Quinn et al., 2007). Radiative impacts of aerosols in the Arctic are marked by complex feedbacks between aerosols, clouds, radiation, sea ice and transport processes and thus remained difficult to understand (Quinn et al., 2007, :109).

Within a few years, the understanding of black carbon improved as several scholars published new modelling approaches. Radiative forcing from black carbon on snow appeared to be positive, though lower than previously suggested (between 0.03 to 0.11 W/m^2) (Flanner et al., 2009; Jacobson, 2010). The *AMAP Technical Report on the Impact of Black Carbon on Arctic Climate* incorporated these new findings and states that despite the uncertainties in determining the radiative effects of black carbon, some of its features were clear: Both the decrease in atmospheric albedo and the decrease of surface albedo from black carbon turn out to show a positive sign. Thus, black carbon from Arctic haze is assumed to be causally linked to a warming local Arctic climate and increased or premature ice melts (AMAP, 2011). This, in turn, was associated with accelerating effects on global warming (Ramanathan and Carmichael, 2008).

5.3.3.5 Summary: The Shifting Scientific Understanding of Arctic Haze

Unique conditions aggravate research in the Arctic in several ways: remoteness, extreme sub-zero temperatures, ice and snow are practical factors that challenge researchers and especially research equipment to the edge. Infrastructure is underdeveloped and standard equipment was never designed for use under such conditions. Secondly, due to those conditions, previous scientific knowledge gained from other regions cannot be easily transfered. Hence much research in the Arctic had to start from scratch. Both sources of difficulties were formulated in numerous publications. Thirdly, political reasons during the 'cold war' period limited scientific exchange and cross border research projects, such as airplane measurements.

As the previous section shows, the history of scientific knowledge on different aspects of Arctic haze is marked by detours, deadlocks and uncertainties. After its discovery, the **sources** of Arctic haze were considered to be a natural phenomenon. but further investigations in the 1980s pointed to anthropogenic sources. As local sources seemed an implausible explanation, scholars searched for sources in the industrialized northern hemisphere. This was supported by findings on possible atmospheric pathways. Findings on **long-range transport** through an interaction between meteorological high- and low-pressure systems changed standing paradigms about aerosol transports and existing models of aerosol transport had to be fundamentally revised. The new models were supported by new empirical measures and it became clear that (a) Arctic haze is of anthropogenic origin and (b) traveled from sources in Eurasia and North-America towards the Arctic.

Determining the **composition** of Arctic haze proved to be limited by extreme research conditions in the early days of research. But as methods advanced, the actual composition of Arctic haze could be traced more accurately and the chemical fingerprint gave further confidence to hypotheses on sources and pathways. Insights on the components of Arctic haze led to considerations on how it might affect the Arctic region and research shifted towards the issue in the late 1979s and early 1980s. Since the biggest fraction of Arctic haze was found to be SO_4^{2-}, the acidifying properties of which were known from previous works on SO_4^{2-} in other regions, research focused in the beginning on SO_4^{2-}. Even though SO_4^{2-} was thouht to disturb the natural equilibrium of Arctic flora and fauna, its effects were assumed to diminish with regulatory steps taken by CLRTAP. Research shifted towards possible climatic effects from black carbon in Arctic haze[24].

During the first phase on research on possible **effects** of Arctic haze, the understanding of aerosols was still in its infancy. It seemed reasonable to assume that

[24] This goes in parallels with a broader shift in scientific research 'from acid' to climate change.

Arctic haze would somehow perturb the radiative budget of the Arctic. Additionally, it seemed very likely that the Arctic radiation budget was extremely sensitive to perturbation due to extreme seasonal changes in the budget and high surface albedo of the snow-white surface. During the 1980s, Arctic haze was modeled as a solar radiation absorbing layer which would lead to a raise temperatures within the atmosphere and lower surface temperatures with a slight net cooling effect. The models were confirmed by empirical measurements, though researchers in most instances emphasized the many preliminary assumptions and uncertainties in their models and measurements. Additionally, the publications differ regarding the magnitude they attribute to the net cooling effect.

Even though some researches raised concerns about a possible additional effect from depositional black carbon on Arctic snow as early as the 1980s, the issue did not gain much attention before the year 2000. Researchers found evidence that black carbon on the snow-covered Arctics could decrease surface albedo. This could substantially contribute to snow-melt, making black carbon the second most effective actual driver of global climate change. Yet again, it seemed as if this process would only appear under particular conditions and much was uncertain about the actual magnitude of this effect. Though for a long period, it remained unclear whether the solar radiation absorbing cooling effect was offset by the albedo decreasing effect, the AMAP report declared that in the light of all evidence, it is likely that Arctic haze has a heating effect than a cooling effect, making it a climate forcer.

In conclusion, the actual role of Arctic haze remained unclear for decades. Arctic haze research experienced two major shifts: From hypotheses on natural origins to hypotheses on anthropogenic origins and from hypothesis on a net cooling effect to hypothesis on a net heating effect. While contradictions between different models and diverging empirical findings on the sources of Arctic haze have been resolved at latest by the 1990s, aerosol research and research on black carbon still bears complex uncertainty. Even though the actual effect of Arctic haze for the Arctic (net cooling or net heating) has not been clarified beyond any doubt, the AMAP-report of 2011 states that in the light of all reviewed scientific research, it seems plausible to assume that Arctic haze has a heating effect rather than a cooling effect. This implies a paradigmatic change from the AMAP-report of 2006 to the AMAP-report of 2011. While the 2006 report stresses that Arctic haze might cool the Arctic climate, the 2011 report clearly warns that it is more likely that Arctic haze warms the Arctic climate with large implications for the global climate.

	1960s	*1970s*	*1980s*	*1990s*	*2000s*	*2010s*
Sources and Emissions	++	++	-	+	- -	- -
Negative Effects	++	++	++	+	+	-
Composition	++	++	+	-	- -	- -
Transport and Migration Patterns	++	+	+	-	- -	- -

TABLE 5.13: Level of Scientific Uncertainty concerning Arctic Haze over Time and Scientific Theme
Uncertainty levels (see section 4.4.1.2): ++ = very high, + = high, % medium, - = low, - - very low

5.3.4 Stages of Political Actions towards Regime Formation

Even though there is no international regime to regulate Arctic haze, there has been a series of considerable international efforts concerning the Arctic environment in general, such as the Rovaniemi-Declaration from 1991 (Arctic Council, 1991) (see section 5.3). This diplomatic initiative led to the signing of the Arctic Environmental Protection Strategy by the Arctic rim states (Canada, Denmark, Finland, Iceland, Norway, Sweden, the USSR and the USA (Arctic Council, 1991, :3)). By signing this document, states have agreed on scientific cooperation and knowledge exchange on selected environmental issues in the Arctic. The initiative was followed by the constitution of the Arctic council, a forum among the Arctic rim states to exchange and coordinate various issues concerning the Arctic (Bloom, 1999). The Arctic council meets biennially at the ministerial level, each meeting concludes with an official joint declaration and several national statements. The aims of the forum are to "[. . .]provide a means for promoting cooperation, coordination and interaction among the Arctic states [. . .] on common Arctic issues, in particular issues of sustainable development and environmental protection in the Arctic." (Arctic Council, 1991, :2). Similar to comparable international environmental organizations, the political deliverables of the Arctic Council are mainly policy recommendations and guidelines, agreed upon through consensual voting. However, it also established a substantial scientific body to assess various aspects of the Arctic environment. Each ministerial meeting is preceded by a collaborative assessment report from AMAP, which was founded and funded by the Arctic Council member states.

The analysis of this study will focus on the political processes within the Arctic Council for several reasons: First of all, the Council was the first multilateral political forum to which the issue of Arctic haze was presented by a scientific body. Secondly, the Arctic Council member states already committed to the aim of environmental protection by signing the founding documents of the Arctic Council and the Arctic Environmental Protection Strategy. It can therefore be reasonably assumed that these states have some concern for the well-being of the Arctic region. Thirdly, emissions that contribute to Arctic haze are largely sourced within the territory of Arctic council members. A change in behavior of Arctic Council member states could therefore actually make an impact on the problem. Fourth, though designed as a forum, the Arctic Council has already produced legally binding multilateral environmental agreements, such as the 'Agreement on Cooperation on Marine Oil Pollution' (Arctic Council, 2012). This shows that the forum is, in principle, an adequate organization with the ability to produce legally binding international environmental agreements. A review on the official declarations, as well as notes, minutes, press releases and national statements (where available), show how the political considerations on Arctic haze and especially the issue of black carbon have shifted over the years.

The issue of Arctic haze was presented to the Arctic Council in 2000 by the Arctic Monitoring and Assessment Programme (AMAP). It was, however, framed as a matter of acidification, which is reflected by the national statements and the final declaration.

The member states commited to support the by that time still pending CLTARP-Protocols on Acidification, POPs and Heavy Metals and encourage member states to ratify the protocols. At the same ministerial meeting, the issue of climate change in the Arctic was discussed. The major concerns according to individual statements and the official declaration was the rapid climatic change in the Arctic. However, the Arctic was regarded merely as a receptor rather than a possible driver for global climate change. Therefore, national statements and final declarations circle around balancing economic opportunities resulting from climate change[25] with environmental care for the Arctic. National statements (for example the statement by the USA) emphasize the necessity for further knowledge prior to political action on the issue of climate change.

While this view on climate change continued with the subsequent ministerial meetings in 2004 and 2006, member states acknowledged anthropogenic sources for climate change and the need for mitigation of greenhouse gases in official declaration of 2009. Additionally, the declaration "[...]note[s] the role that shorter-lived climate forcers such as black carbon, methane and tropospheric ozone precursors *may* play in Arctic climate change, and recognize that reductions of emissions *have the potential* to slow the rate of Arctic snow, sea ice and sheet ice melting in the near-term" (emphasizes added). This was the first political recognition of possible effects from black carbon in the Arctic and changed the previous perception of the Arctic as a mere receptor of global climate change.

At the next ministerial meeting in 2011, member states signed a declaration that "[...]encourage[s] Arctic states to implement, *as appropriate in their national circumstances* relevant recommendations for reducing emissions of black carbon" (emphasize added). The need for further multilateral action on black carbon emission reduction is also emphasized by national statements while other states continue to emphasize the economic opportunities within the Arctic from climate

[25] As new trading routes and a possible exploitation of natural ressources.

change. The declaration of 2013 points in the same direction. Black carbon is recognized as a source for climate change and member states decided to set up a task force to develope arrangements on actions to achieve enhanced black carbon reductions in the Arctic until the next ministerial meeting in 2015 (Arctic Council, 2012).

5.3.5 A Cost-Benefit-Configuration of Arctic Haze Regulation

It has been convincingly argued in section 5.3.1 that the main motive for joint measures on Arctic haze through a multilateral agreement could be to avert negative effects from climate change. Since the negative climatic effects of black carbon work on a much shorter time scale than for example CO_2, reducing black carbon could be an efficient (though not sufficient) short-term instrument to combat global climate change. In addition, as the review of the historic scientific development shows, possible impacts from Arctic haze on climate change stem from black carbon. Reducing negative climatic effects from Arctic haze hence requires a reduction in black carbon emissions. This, in turn, could lead to a reduction of climatic effects and climate change vulnerability. However, this would only be the case if the negative climatic effects of black carbon really exist as proposed, meaning that the hypotheses on a net heating effect from Arctic haze really is valid. It has been emphasized in the previous section how controversially this link has been discussed, as there are two groups of models that predict oppositional effects from Arctic haze: one group predicting a net cooling effect, the other a net heating effect. If the latter is the 'true' model, black carbon emission cuts are an effective means to reduce climate change vulnerability, reducing black carbon emissions would actually raise climate change vulnerability. A cost-benefit-profile oscillates between these extreme points.

Data of black carbon emissions is acquired from the AMAP Technical Report on the Impact of Black Carbon on Arctic Climate (AMAP, 2011) which compiles data from different black carbon inventories. Black carbon emissions are made available for Arctic Council members for the year 2000. The report was published in 2011 and its results were presented to the Arctic Council in 2013. In the context of this study, relying on compiled AMAP data rather than direct emission data (Bond et al., 2007; Lamarque et al., 2010) ensures that the data considered in this study was actually available to Arctic Council member states.

Data on climate change vulnerability is taken from the UNEP Environmental Vulnerability Index (Kaly et al., 1999). The Index is constructed from national data, climate change vulnerability is a subindex. The Index ranges from 0 (Resilient) to 7 (Extremely vulnerable).

Country	**Climate Change Vulnerability Score**[26]	**Black Carbon Emissions (Gg/y)**[27]
Canada	3.08	52
Denmark	4.31	24,4
Finland	2.61	24,4
Iceland	3.85	24,4
Norway	3.15	24,4
The Russian Federation	2.73	516,5
Sweden	3.08	24,4
USA	3.23	765,5

TABLE 5.14: Climate Change Vulnerability
Source: Climate Vulnerability Index (Kaly et al., 1999); Technical Report on the Impact of Black Carbon on Arctic Climate (AMAP, 2011)

Data on climate change vulnerability and black carbon emissions make it possible to identify three groups of polluters: Russia and the USA show very high emissions of black carbon, followed by Canada with a medium value and Denmark, Finland and Iceland who emit only about half as much black carbon as the Nordic States and only a small fraction of the US' and the Russian Federation's share. Concerning vulnerability scores, only Denmark scores above the median. The Russian Federation and Finland score lowest, but generally, most countries score around the median. This implies that they all face a medium climate change vulnerability and all countries are rather symmetrical in their climate change vulnerability.

5.3.6 Conclusions

Both scientific progress and political action on Arctic haze have evolved in different stages. In the early years between 1975 and 1981, it was believed that Arctic haze had natural sources from Asian deserts. It was therefore regarded as a pure scientific matter that could hardly be influenced by human action. Its anthropogenic nature was discovered between the mid 1980s to 1990, but in absence of local emission sites, its origin remained enigmatic. This changed after the discovery of long-range transport in the 1990s and with more accurate measurements of chemical fingerprints which made it possible to trace back emissions to actual sources and regions.

However, during this time period (roughly from 1985-1995), Arctic haze was assumed to consist of mainly SO_2, which was already regulated by the CLTRAP and additional political action seemed obsolete as measurements showed decreasing SO_2 concentrations in the Arctic. This situation changed when researchers brought the issue of black carbon in Arctic haze into the political debate. Even though scientific research provided robust arguments for climatic effects of black carbon in the Arctic, it remained unclear in which direction and to what magnitude temperatures would change due to Arctic haze. Two oppositional effects were known and during this period and model calculations did not allow conclusions about which effect would dominate, i.e. whether Arctic haze had a cooling or a warming effect. As a consequence, political action was directed at furthering the understanding of the actual effects from Arctic haze.

The most recent scientific advances still point out complications and knowledge gaps, but they imply that Arctic haze overall has a warming effect on the Arctic climate and therefore has the potential to accelerate global climate change through breaking tipping points. Not surprisingly, political actors most recently called for an exploration of coordinated political action to reduce black carbon emissions. For that reason, Arctic Council members states agreed to set up an inventory to measure black carbon emissions in the first place.

The case of Arctic haze is informative and most suitable for this comparative case study for several reasons. First of all, both the scientific process and the political process involve a manageable time-span and amount of actors. This, on the one hand, facilitates an in-depth understanding of both processes, and challenges existing theoretical approaches to explain regime formation. The Arctic haze phenomenon was studied and researched by a small, unified group of international researchers, who were collaborating, publishing and exchanging at scientific conferences over the whole period of time. They shared a similar understanding on the issue and had access to the political arena as their research results were frequently presented to political decision makers. The network can therefore be perceived as a prototypical 'epistemic community' as Haas (1992a) defines it. Hence, a knowledge-base approach would argue that these factors would highly facilitate a regime formation process.

According to an interest-based approach, the structural factors of a limited number of political decision-makers that, in principle, were committed to protecting the Arctic environment by signing the Arctic environmental protection strategy would speak (however weakly) in favor of a successful regime formation process according to an interest-based approach. Both theoretical approaches would lead us to expect an existing regime and it thus seems even more surprising that no such regime exists.

	Before 1975	*1975 – 1981*	*1981 – 1990*	*1991 – 2000*	*After 2001*
Scientific Process	First discovery of Arctic haze by pilots, who assumed natural sources. No knowledge about its composition nor on any negative effects.	Findings on increased particle concentrations of uncertain origin. Composition of Arctic haze did not fit standard transport models. Limited knowledge on composition. SO_4^{2-} in Arctic haze raised concerns about acidification	Models on particle transport to the Arctic evolved. Improved, but still limited understanding on composition shows high proportion of black carbon and black carbon becomes the major concern. Anthropogenic sources were confirmed through airplane measurements. Two contradicting theories on thermal effects of Black carbon with oppositional implications for global climate change evolved.	Meteorological models on particle transport are repeatedly confirmed through airplane measurements. Detailed information on the composition of Arctic haze is made available. Share of black carbon was found to be higher than assumed. Integration of scientific knowledge on Arctic haze through the AMAP assessment report.	Accumulating evidence that Arctic haze has a heating (instead of a cooling) effect for Arctic climate. Yet, remaining uncertainties about the magnitude of the effect.
Cost-Benefit Configuration	Uncertain Costs, uncertain benefits	Uncertain costs, uncertain benefits	Uncertain costs, uncertain benefits	High costs, uncertain benefits.	High costs, uncertain benefits.
Expected Political Action	Call for / investment in more research, coordination of research efforts	Call for / investment in more research, coordination of research efforts	Call for / investment in more research, coordination of research efforts	No institutionalized political cooperation on Arctic haze	No institutionalized political cooperation on Arctic haze
Observed Political Process	No political action concerning Arctic haze at the international level	No political action concerning Arctic haze at the international level	No political action concerning Arctic haze at the international level	Early political action on the international level. 1991: Rovaniemi-Declaration: Arctic Environmental Protection Strategy by Arctic rim states. Foundation of the Arctic council. Foundation of AMAP.	Arctic Council parties acknowledge black carbon as a *potential* environmental issue and declare an intent to reduce black carbon emissions. Furthermore, Arctic Council parties agree to further investigate the issue through an institutionalized research group and reconsider the issue in 2015.

TABLE 5.15: Milestones in Scientific Research and Political Action on Arctic Haze

5.4 The Non-Regime on International Forest Protection

> "If you chop a tree, you know what happens to carbon - but what this is causing is largely unknown"
>
> Evelyn Trines *Secretariat of the Framework Convention on Climate Change*

Protecting forests on a global scale has been on the agenda of international negotiators for over two decades. But despite these efforts, a multilateral agreement on forest protection is yet to be seen. More than once, governments, international agencies and NGOs have demanded global action to protect forests in order to avert climate change. Nevertheless, the nexus between deforestation and climate change involves a rather long and scientifically uncertain causal chain. Especially the relationship between a long-term increase in and a short-term albedo effect is a complex one.

The series of political attempt and failure motivates the inclusion of the case in this comparative study. The issue sparked high-level negotiations with the engagement of various international agencies for decades without producing an outcome in the form of a legally binding agreement. It is therefore a very prominent case of a non-regime. The puzzle of a non-regime *despite* high-level political action and the role of scientific uncertainty within this context adds additional explanatory value to the comparative perspective of this study.

Though deforestation has multiple effects soil erosion, endangered species or indigenous peoples, this work exclusively focuses on deforestation in the context of climate change. Climate change has been the most prominent issue that has so far been addressed during negotiations on forest protection. The IPCC estimates that around 17% of global CO_2 emissions are caused by deforestation (IPCC, 2007c). Even though several local effects from deforestation may appear to be more urgent, climate change is the most prominent *transboundary* effect and therefore bears the most prominent transnational collective-action-dilemma in the context of deforestation. For example, soil erosion in Brazil has no negative effect on Swedish territory; melting ice-shield and glaciers as a result from global climate change (to which deforestations contributes through the emission of CO_2 (IPCC, 2007c)) however does. Therefore, the rationale for engaging in a multilateral agreement on forest protection for countries like Sweden is climate change.

Additionally, the case study focuses on the time period between 1950 and 2005, because most scientific advancement appeared within this period and, secondly, because the time period covers the political efforts that were directed at negotiating an agreement on forest protection. This period, however, does not cover recent political activities under the UN Program 'Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries'. The program supports developing countries in their efforts to reduce domestic deforestation through financial compensation. Arguably, REDD is the binding multilateral agreement that derived from the political efforts on deforestation. Not including the process towards REDD would seriously bias the case study. However, as this case study must be regarded as a part of a bigger research project, including the political process leading to REDD would go beyond the scope of this study. For rather pragmatic reasons, political processes on an international level beyond 2005 are excluded from this study.

Forests cover approximately 30% of the earth's surface. The tropical rain forest and the boreal forest make up for about 90% of global forests. 53% of all global forests are used for commercial purposes (FAO, 2010). Forests provide multiple services to humans and wildlife. They are a habitat for a huge and diverse flora and fauna, they provide recreation facilities to humans, protect land and water resources, improve air quality and mitigate climate change (FAO, 2005). Additionally, forests are an important resource for raw material across multiple industry sectors and a resource for energy (FAO, 2005). As "the earth's lungs", forests catalyze CO_2 into oxygen and sequestrate carbon.

Although forest land is reduced through fires, draughts, storms and other natural phenomena, this work focuses on human activities that directly contribute to deforestation for two reasons: First of all, according to the FAO (1990) report on global forests, natural sources for deforestation are negligibly small and secondly, only human activity can be addressed by political action. The term ‘deforestation’ hence refers in this work to the anthropogenic conversion of forest land into non-forest land. This excludes human activities that indirectly decrease woodland areas, such as the acidification of soil or toxic waste disposal.

This rather narrow definition of deforestation follows the official FAO definition and reflects the political debates on anthropogenic deforestation (see section **??**). Forests are mainly reduced through commercial logging and the conversion of forest land to farm-land for agricultural purposes (FAO, 2010). Conversion of forest areas to farmland appears mainly in the tropical regions as boreal latitudes are climatically unfitting for agricultural use.

On a global scale, an estimated 2-5% of forest is lost each year (FAO, 2010). As a global political issue, deforestation is mainly discussed in the context of global climate change (Gibbard et al., 2005). Two parameters impact on global average temperatures: on the one hand, the reflectiveness (or albedo) of the earth’s surface which influences the solar energy-budget. In simplification, high albedo leads to more reflection of solar radiation and less absorption of solar energy on the surface and hence – in general – less global warming. The higher surface albedo, the lower are surface temperatures. On the other hand, ‘green-house gases’ (with CO_2 among the most effective ones) determine how much solar energy is radiated back to space through the atmosphere (see: IPCC (1990) :47). More simply put, a high concentration of green house gases leads to an acceleration of global warming.

Forests interfere with both of these parameters. On the one hand, forests store and sequestrate atmospheric carbon from CO_2. Deforestation decreases the carbon sequestration capacity of forests on a global scale. Secondly, additional CO_2 is released into the atmosphere through deforestation[28]. Forests also interfere

[28] The amount of CO_2 released to the atmosphere, however, highly depends on the purpose of deforestation. Burning wood to convert forestland into farmland or for heating purposes releases

with surface albedo (Bala et al., 2007). They are, in general, more reflective than grassland, deserts and most farmland. However, they are by far less reflective than snow-fields (Bonan, 2008; Lee et al., 2011). Therefore, the sign and magnitude of albedo-effect changes from deforestation highly depends on its location. Converting woodland into farmland might decrease albedo and therefore increase climate change. Converting woodland into snow-fields has the opposite effect. Hence, deforestation does not have a single-lined effect on surface albedo. The albedo effect of deforestation highly depends on the location.

Additionally, forests also effect the accumulation of vapor and clouds which changes precipitation patterns. A change in precipitation pattern, in turn, indirectly changes surface albedo at high latitudes. Less precipitation results in less snowfall which reduces surface albedo and leads to an increase in temperatures. In tropical latitudes, changes in precipitation patterns increase surface temperatures, Therefore, in general, deforestation causes a net warming in low latitudes and a net cooling in high latitudes (Gibbard et al., 2005). Within this system of interacting effects, science is highly at odds as to what effect dominates the other.

The protection of global forests has raised political concerns, but these concerns resulted in little political action. Even though FAO has emphasized the need for an internationally coordinated forest policy as early as 1958 (FAO, 1958), the loss of woodland areas has started to raise political concern on a transnational level for the first time during the 1980s. The issue is marginally addressed by a number of multilateral agreements such as the International Tropical Timber Trade Agreement (ITTA), the United Nations Framework on Climate Change (UNFCCC) the Convention on Biodiversity (CBD) and the Convention to Combat Desertification (CCD). However, none of theses agreements explicitly addresses the issue of deforestation. ITTA is regionally limited to tropical forests and promotes sustainable timber trade, therefore addressing deforestation only indirectly. The UNFCCC and the CBD follow the same direction. They both address the issue of deforestation, but do not contain legally binding instruments for forest protection nor do

most stored carbon into the atmosphere. Wood products (used for example in construction work or furniture), on the other hand, often have a longer lifetime than trees in nature, since the wood is purposely protected against weathering and other degradation processes they allocate resources to forest protection. Even though forests are considered to be a crucial instrument to avoid desertification, the CCD has not included it into its text. Additionally, implementation plans of the CCD are regional in scope (Dimitrov, 2006, :101ff). A comprehensive multilateral agreement that explicitly targets deforestation on a global scale is still missing, despite a long tradition of negotiation rounds.

It seems puzzling that forest protection has been recognized by decision-makers, has been repeatedly addressed within a number of international negotiations and is partially included in a series of multilateral agreements, but a comprehensive multilateral agreement that considers the issue in the context of climate change is still missing. The theoretical argument presented in chapter 3 states that regime formation depends on the interests of states. Furthermore, the argument states that the formation of states interests highly depends on how states perceive the issue. On transnational environmental issues, the perception of the issue is influenced by scientific knowledge and some aspects remain – due to the complexity of environmental issues – uncertain. The argument states that regime formation depends on what aspect of an environmental issue remains uncertain. In the light of the theoretical argument, we would expect that (a) the configuration of scientific knowledge was obstructive, meaning that either costs were high while benefits were uncertain, or costs were uncertain while benefits were considered to be low. Or (b) that states were highly dissimilar in their perception of the issue. In either case, we would expect that countries that supported international forests protection had a rather conducive profile and countries that opposed an international environmental agreement had a rather obstructive profile.

5.4.1 Defining Costs, Benefits and Uncertainties on International Forest Protection

Commercial logging and farmland conversion are the most important causes for deforestation (FAO, 2010). Hence, an international agreement to protect forests from deforestation would have to regulate both activities. Costs from regime formation were previously defined as direct economic costs from international regulation. The direct economic costs from regulations on commercial logging and farmland conversion depends on the economic involvement of a country in these activities.

Vulnerability from deforestation occurs from the loss of its services, such as water and land protection. However, these effects are occur rather locally. They are caused by local deforestation and can therefore be only an issue of domestic policy, not an issue of international regulations. Nevertheless, deforestation has a potential transboundary dimension in the context of climate change as local deforestation can contribute to global CO_2 concentration which can accelerate climate change. Hence, vulnerability in the context of a global agreement on deforestation is regarded as vulnerability from climate change.

Both parameters – economic costs and vulnerability – can be affected by scientific uncertainty. Concerning *costs from an international agreement*, states depend on data on domestic logging and data on farmland conversion. Data on both activities might not be available or difficult to assess. Especially data on illegal logging and farmland conversion, which play a significant role in some regions, might be hard to obtain. With *vulnerability from deforestation*, the causal link between deforestation and climate change has been – and still is – heavily debated as neither magnitude nor direction are perfectly clear.

5.4.2 Outline of the Case-Study

To retrace the scientific process and – at the same time – ensure comparability across cases, this case study proceeds similarly to the previous case studies in this work. As a first step, the scientific journals *Nature* and *Science* are scanned for publications on deforestation. Both journals have been scanned for the keywords *deforestation* between the years 1920 and 2014. Additionally, the keyword *deforestation* has been searched in conjunction with *climate change*. As a result, 51 articles were identified as highly relevant to the issue. Additionally, as in the previous case-studies of this work, an citation analysis using 'CiteSpace' has been performed to identify highly influential contributions to the body of scientific knowledge across scientific journals. This resulted in additional 7 journal articles. These publications were scanned for research themes and scientific uncertainty, using qualitative content analysis (Mayring, 2010) and applying the coding-sceme on scientific uncertainty (see subsection 4.4.1.2). For an overview on the reviewed scientific contributions, see the appendix.

In addition to the primary sources of scientific literature, the case-study includes secondary literature and official assessment reports. Dimitrov (2006) published a case-study on deforestation that reflects to some part the state of scientific knowledge until the year 2001. Additionally, the UN Food and Agricultural Organization (FAO) periodically publishes assessment reports on the state of global forests, which are included in this study.

Dimitrov (2005, 2006)'s publications and Humphreys (2006)'s book also serve as a source to retrace political action on international forest protection. Apart from that, international negotiations within several fora that have addressed the issue of international forests since the 1992 forest principles have been covered in depth by the *Earths Negotiation Bulletin (ENB)*, a reporting service that summarizes the process of different international negotiations to a certain topic, in this case forests. The reports are a result of the observation of individual reporters that physically participated at the negotiations. They reports reflect individual standpoints of negotiators, highlights, dead-ends and break-throughs. Additionally, the United Nations Forest Forum (UNFF) provides documentation on each session from the three most important arenas in which forest issues were discussed. The following sections rest on this body of literature.

5.4.3 Stages of Scientific Knowledge

5.4.3.1 Sources and Extent of Deforestation

The sources of deforestation as defined in the previous section are linked to clearly observable human activity and have never been an issue of controversy. Researchers agree that human activities account for the largest part of deforestation. These include commercial logging, farming, settlement programs and mining (FAO, 1995). Both rates of deforestation and dominating sources and human activities differ across regions. While the main cause for deforestation in Africa is the conversion of forest areas into farmland, settlement schemes and hydroelectric projects are the main cause for deforestation in South America. Deforestation in Asia is caused by a mix of different factors (Dimitrov, 2006; FAO, 1995).

Before rates of deforestation or other changes in wood area could be assessed, stocks on forestland had to be taken as a baseline measure. This proved to be more difficult than one might have expected. Remoteness and the absence of satellites plagued early efforts to estimate global forest land. In an early attempt, Zon and Sparhawk (1923) developed a first comprehensive estimate on global forest areas in 1923 which was developed further between 1928 and 1931 (FAO, 1948). The International Institute of Agriculture in Rome (a predecessor of FAO) collected information on domestic forests provided by national governments. The data was summarized and published in 1946 by FAO as the first assessment on global forests (FAO, 1948). The assessments, however, suffered from a lack of reliable forest inventory information, which existed and continue to exist in many countries. Additionally, commonly accepted definitions of some of the more important forestry terms were lacking. Hence, neither qualitative descriptions nor quantitative estimates were unambiguously clear (FAO, 1948).

FAO continued its work and the first official assessment on global forests and the extent of deforestation has been performed by FAO as early as 1953 (FAO, 1958). Inventory data was acquired through questionnaires answered by individual countries. This was the first attempt to globally estimate the true amount of forest land, and the inventory was repeated after a five-year period. But once again, early efforts suffered from unclear definitions that changed over the reporting periods. Hence, national data and international assessment reports lacked comparability and did not allow to account for changes in global forest lands. The issue of non-uniform definitions continued over the years. It was not until the FAO global assessment report in 1990 before changes in forest lands could be assessed sufficiently (FAO, 1990). The report stated a yearly net forest loss of 9.9 million hectares between 1980 and 1990 (FAO, 1990). An increasing loss of 11.3 million hectares was reported in 1995, but the numbers declined in 2000 (9.4 million hectares), in 2005 (8.9 million hectares) and dropped to 5.2 million hectares in 2010 (FAO, 1995, 2000, 2005, 2010).

The reliability of FAO figures, however, has raised some concerns. Especially estimates of changes in tropical rain forests produced large uncertainties since the estimates of FAO did not correspond with satellite measurements (Achard et al., 2002). Satellite measurements indicate that FAO figures overestimate global forest loss. Despite doubts in their accuracy, FAO data is still the most reliable and most comprehensive data on changes in forest land most accurately. It was frequently referred to during international meetings on forest protection (Dimitrov, 2006, :118).

Even though scholars had trouble to define and assess changes in forest areas, improvements in methods led to a good picture of the actual loss of forest land. This means that knowledge on the source and extent of deforestation was rather certain after the FAO assessment in 1990. In the context of this study, this implicates that countries had a good idea of how much forest area was lost annually by logging and farming. Hence, states could estimate their individual cost from internationally regulating deforestation.

5.4.3.2 Effects of Deforestation on Global Climate Change

Relevant effects from deforestation appear in the form of a loss of forest services, such as a loss of resources for raw material or the protection of land and water.

While most of these effects are local in nature, deforestation has a transboundary dimension in the context of global climate change. In the mid 1970s, shortly after Keeling (1970) published his ground-breaking findings on increasing CO_2 concentrations in the atmosphere (Keeling curve), researches began to investigate emissions and the fate of CO_2. Since modeled CO_2 emissions exceeded atmospheric concentrations, scholars were puzzled by the "missing sink" for carbon and researchers disagreed whether the sink was rather to be found in the ocean or in terrestrial forests (Fan et al., 1998). Nevertheless, though it remained unclear how much CO_2 was absorbed by terrestrial forests, scholars began to investigate deforestation as a potential source for atmospheric CO_2. In an early attempt, Bolin (1977) estimates total CO_2 emissions from deforestation and suggests a strong influence form deforestation on the global carbon cycle[29]. His data indicated that deforestation might contribute to an increase of atmospheric CO_2.

In the 1980s, a small number of publications addressed the contribution of deforestation to CO_2 concentrations with a focus on decreasing tropical forests. Woodwell et al. (1983) published model-based results on the amount of carbon released into the atmosphere due to deforestation of tropical rain forests; they already put the result in the context of climate change. They found that – in contradiction to previous publications – the fertilization effect of increasing CO_2 concentrations did not outbalance the CO_2 emission effect from deforestation. They, however, emphasize that their results should be interpreted with caution, as their empirical data on deforestation was rather fragile.

During the 1990s, studies coupled newly acquired inventory data on forests with models on carbon storage in wood and confirmed the hypothesis of tropical rainforest as a significant carbon sink (Grace et al., 1995; Phillips et al., 1998; Wisniewski et al., 1994). However, the estimates were model-based and lacked sufficient data. For example, Shukla et al. (1990) note that it is "[...]difficult to draw any definite conclusions about the global effects of Amazon deforestation from this study." (Shukla et al., 1990, :1324). Despite the uncertainties, the work was picked up

[29]The carbon cycle describes the exchange of carbon between oceans, terrestrial land mass and the atmosphere. For a comprehensive explanation, see for example: (IPCC, 2007c)

by FAO's assessment work in 1995 (FAO, 1995). And the IPCC (1996)-report accounts that 23% of anthropogenic CO_2 emissions are caused by deforestation. The However, nearly every statement on deforestation in the IPCC report from 1996 emphasized how scarce data on deforestation is and how many mechanisms are still poorly understood (Dimitrov, 2006, :119). During that time period, it remained unclear whether the tropical rainforest is a sink or a source for atmospheric CO_2, as data and measurement instruments remained insufficient (Enting et al., 1995).

The majority of research focused merely on tropical forests, neglecting the large areas of boreal forests. Bonan et al. (1992) were among the first scholars to study the effects of boreal forests on the global climate. Their model did not only focus on carbon emissions from deforestation, but also included changes in surface albedo as a result of changing boreal vegetation. They found that the removal of boreal forest decreases surface temperatures since it increases snow fields with high albedo. According to their study, this might outbalance the CO_2-induced rise of global mean temperatures.

The net effect from boreal deforestation, however, depends on the *method*, e.g. on how forest is removed. While studies indicate that logging will create sustainable snowfields with a high albedo, other studies indicate how burning boreal forests can contribute to *Arctic haze*, which potentially contributes to climate change (Randerson et al., 2006; Stocks et al., 1998).

Bala et al. (2007) have coupled a global carbon cycle with a climate model their results have indicated that the albedo effect would overwhelm a CO_2-induced rise of global mean temperatures. Hence, according to their publication, global deforestation would have a net cooling effect for the global climate. However, their results are based on computer simulations which assume the highly unlikely case of total global forest loss and neglect the mentioned differences in consequences due to the method of deforestation.

During the 2000s, progress was made on estimating carbon stocks in forests. This also allowed to estimate carbon flows between forests and the atmosphere. Newly developed models confirm that global forests are a net sink for carbon, despite deforestation. However, terrestrial CO_2 uptake and its distribution remains an issue of scientific debate. For example, (Stephens et al., 2007) show how previous research has overestimated boreal sinks and has underestimated tropical sinks.

Besides estimating carbon stocks in forests, researches addressed the complex relationship between carbon release, evaporative cooling and albedo enhancement in the context of deforestation. While research so far focused on either tropical forests *or* boreal forests, scientists recently have started to take a global perspective on deforestation to assess the global net effects. Bonan (2008) provided an overview on research on forests and climate change. He differentiated three different forest types (tropical, temperate and boreal forests). Secondly, he compared each forest type with the non-trees-scenario and showed how each type has a different effect on carbon release, evaporative cooling and albedo. For tropical forests, the non-tree-scenario shows an increase of atmospheric CO_2 and a decrease of evaporative cooling, while albedo change remains moderate. Similarly, the non-trees-scenario for temperate forests shows higher CO_2 concentration while albedo change is moderate. Additionally, Bonan (2008) has emphasized that evaporative cooling is only poorly understood for temperate forests. Boreal forest store less carbon, but the non-trees-scenario shows a sharp increase in albedo values in case non-tree land in the boreal region is assumed to be covered by snow.

Bonan (2008)'s study is a remarkable attempt to draw conclusions on the complex role that forests and the removal of forests play. However, it also shows large gaps in knowledge on deforestation: "The combined carbon cycle and biogeophysical effect of tropical forests may cool global climate, but their resilience to drought, their status as carbon sinks, interactions of fires, aerosols, and reactive gases with climate, and the effects of small-scale deforestation on clouds and precipitation are key unknowns. The climate forcing of boreal forests is less certain. Low surface albedo may outweigh carbon sequestration so that boreal forests warm global climate, but the net forcing from fire must also be considered, as well as effects of disturbance and stand age on surface fluxes. The climate benefit of temperate forests is most uncertain. Reforestation and afforestation may sequester carbon, but the albedo and evaporative forcing are moderate compared with other forests and the evaporative influence is unclear. Much of our knowledge of forest influences on climate, and our ability to inform climate change mitigation policy, comes from models. Models of climate and the biosphere are abstractions of complex physical, chemical, and biological processes in the Earth system. Extrapolation of process-level understanding of ecosystem functioning gained from laboratory experiments or site-specific field studies to large-scale climate models remains a daunting challenge."(Bonan, 2008, :1448-1449).

Deforestation has diverse effects on the global climate, depending on where and how it occurs. Forests can either mitigate or accelerate climate change. On a regional level, as well as on a global level, it remains highly unclear what effect dominates the other. It is therefore impossible to draw unambiguous conclusion about the effects of deforestation on climate change. Regarding the uncertainty whether deforestation enhances or impedes global climate change, benefits in terms of reduced vulnerability were and still are difficult to assess. In the light of the argument, this means that benefits from regulation were uncertain to all involved countries.

5.4.3.3 Summary: The Uncertain Consequences of Deforestation

The earliest attempts to estimate global forest lands in the 1950s were plagued by a lack of sufficient methods and uniform definitions of what a forest actually is. With repeated assessments by FAO methods improved, and data reported from countries started to follow a uniform reporting protocol (Dimitrov, 2005). Even though the questionnaire-based data on deforestation from FAO is not beyond any doubt, it is still considered to be the most reliable source to determine deforestation rates (Dimitrov, 2006, :112).

Concerning the effects of deforestation, scientific knowledge has made some progress over the past decades, but is still highly uncertain on many issues. As disturbances in the carbon cycle from anthropogenic CO_2 emissions were assumed to influence the global climate in the early 1980s, research mainly focused on the amount of carbon that was sequestrated in forests, especially tropical rain forests. It was believed that deforestation would contribute to climate change through emitting additional CO_2. This view was, however, set in perspective as researchers suggested that other forest-related mechanisms, such as evaporative cooling and surface albedo, might outbalance the effects from CO_2 emissions. Whether this is the case still remains a matter of scientific debate, as mechanisms are complex and interrelated.

Reviewing the scientific literature on deforestation revealed how knowledge on the sources and the extent of deforestation became progressively more certain, while knowledge on the effects of deforestation remained rather uncertain. Levels of, and changes in scientific uncertainty become more obvious through the application of the coding-scheme from section 4.4.1.2. In simplification, the coding scheme categorizes the level of scientific uncertainty according to the number reasonable theoretical models to explain an issue (the higher the number of contradicting explanatory models, the higher the scientific uncertainty) and the congruence between model predictions and empirical testings. The coding is applied to the previously identified relevant scientific contributions and presented in table 5.16.

	1950s	*1960s*	*1970s*	*1980s*	*1990s*	*2000*
Sources and Extent	++	++	+	+	- -	- -
Negative Effects	++	++	+	+	+	+

TABLE 5.16: Level of Scientific Uncertainty concerning Deforestation over Time and Scientific Theme
Uncertainty levels (see section 4.4.1.2: ++ = very high, + = high, % medium, - = low, - - very low)

As table 5.16 implicates, states had a clear picture of how much deforestation was actually proceeding. As this data was acquired through national questionnaires and collected by FAO, states knew their annual loss in forest area through commercial logging and farmland conversion. Hence, after the annual loss in forest area became determinable in the early 1990s, states could assess their costs from regulation with a sufficient degree of certainty.

5.4.4 Stages of Political Action Towards Regime Formation

The first multilateral initiative that addressed the protection of forests was the regionally limited International Timber Agreement, which was negotiated in 1983. Calls for a multilateral agreement on forest protection on a broader scope entered the international agenda in 1990 at the 16th G8-summit in Houston, where participating states officially declared that "[...]we are ready to begin negotiations, in the appropriate fora, as expeditiously as possible on a global forest convention or agreement, which is needed to curb deforestation, protect biodiversity, stimulate positive forestry actions, and address threats to the world's forests." (G8 Information Centre, 1990).

The idea was picked up by FAO, which introduced the issue at the preparatory meetings to the 1992 United Nations Conference on the Environment and Development (UNECD). However, even though including forest protection into the Rio negotiations was supported by the U.S., Canada and some European nations, it was dismissed due to reluctancy from developing nations like Malaysia and India, who feared that such a treaty would just be in instrument of trade regulations on timber and other wood products (Humphreys, 2006). As a compromise, participants agreed on a set of legally non-binding forest principles that respect the rights of sovereign states on the management of forest resources. Malaysia and India blocked the inclusion of recommendations for a legally binding document in the future (Dimitrov, 2006, :102-103).

The weak achievements from the Rio conference also frustrated participants from national governments. As a response, officials from Canada and Malaysia initiated a further series of meetings to facilitate dialogue and consolidation of approaches to the management, conservation and sustainable development of the worlds forests within the founded Intergovernmental Working Group on Forests (IWGF), which was founded in 1993 (Humphreys, 2006). The group included 32 key forest countries, such as Brazil, U.S.A., Indonesia, Finland, Sweden, and the Russian Federation, as well as IGOs and NGOs. The sessions were held between 1994 and 1995. Officials mainly discussed appropriate criteria and indicators to assess forest management, an aspect that was also included into the final document. The Working Group was explicitly set up as a non-negotiation forum (UN.CSD, 1995). The final report contained a set of recommendations on how future assessments of national forest areas should be conducted and stressed the importance of the development of criteria and indicators. The Working Group agreed that the United Nations Commission on Sustainable Development (UNCSD) should organize the further negotiating process and the concluding report was presented to UNCSD in late 1994 (IISD, 1995, :1-4).

The process continued in 1995 when countries established the Intergovernmental Panel on Forests (IPF) during sessions of the UNCSD to foster an international dialog on forest and to form the Inter-Agency Task Force on Forests (ITFF). The task force included FAO, the World Bank, UNDP, UNEP, the International Tropical Timber Organization (ITTO) and the Secretariat of the Convention on Biodiversity (Grayson, 1997).

Even though the IPF held four meetings between 1995 and 1997 and produced a list of proposals for potential cooperation areas, participants did not agree on further steps towards a multilateral agreement on the issue. The main obstacles were the questions about what kind of agreement should be installed and whether an agreement was needed at all. The creation of a new, comprehensive agreement on global forest protection was merely one option among others under consideration (Dimitrov, 2006, :105).

The negotiation process continued within the International Forum on Forests (IFF), an additional forum which was established in 1997 at the UN General Assembly. Mandate, structure and purpose of the IFF were similar to the IPF

(Humphreys, 2006, :66). In parallel, the issue of creating a multilateral agreement on global forest protection had been discussed during eight official meetings at the UN General Assembly since 1992. However, national positions on the issue remained unchanged with one group supporting a treaty and another group opposing the treaty. Among the supporters were Canada, the Scandinavian countries, France, Switzerland, the Russian Federation, Malaysia, Turkey, South Africa, Senegal and the Czech Republic. Treaty formation was opposed by the U.S.A., Brazil, Australia, New Zealand, Japan, the U.K., Mexico, India, Indonesia and China and several developing countries. Both groups contained industrial and developing countries, forest countries and non-forest countries, and countries with tropical forests and boreal countries (Dimitrov, 2006, :106).

At the fourth and last session of the IFF in 2000, negotiators felt the pressure of producing at least some form of outcome (Humphreys, 2006). However, after long hours of negotiations, consensus could not be reached and the decision on legal action on forest protection was postponed into the future (UN.ESC, 1999). The IFF decided to create a permanent United Nations Forest Forum (UNFF) to continue the dialog (UN, 2001). Furthermore, it was decided that UNFF would evaluate the precess after five years and "[...]consider with a view to recommending the parameters of a mandate for developing a legal framework on all types of forests."[30] (Dimitrov, 2006, :108).

After its establishment, the UNFF met (and still meets) annually with the intensions to consider the possibilities of legal action. However, many observers consider the forum as "talking shop" or even "circus" that repeatedly produces resolutions without any substantial outcome. The institution lacked a clear policy-making or implementation mandate. Despite efforts to strengthen the UNFF as an international institution by some participants, official statements from meetings are nothing more than declarations of intends and recommendations. The report from the latest session in 2013 merely summarizes national activities on non-legally binding instruments on all types of forests.

[30] NGOs named the paragraph the "Monthy Python paragraph".

While progress within the UNFF stagnated, the issue of forest protection popped up again in 2005 in the context of the UNFCCC. The proposal from Papua-Neuguinea and Costa Rica aimed at installing incentives for developing countries to mitigate deforestation through compensational payments.

5.4.5 Summary: Political Action and Lip Service on the Protection of Global Forests

Political efforts towards transnational forest protection have been described as "[. . .]a series of loudly trumpeted non-events" (Westoby, 1989). And, in fact, the output of a high-level negotiation process that has been proceeding since 1990 is surprisingly small. So far, protagonists have produced a number of declarations of intent and some non-binding agreements concerning forest protection. The UNFF describes the outcomes of deliberations within the IPF and IFF as follows: "One of the most important legacies of the IPF/IFF process is the wide-ranging set of approximately 270 proposals for action [. . .]. These proposals provide governments, international organizations, private sector entities and all other major groups guidance on how to further develop, implement and coordinate national and international policies on sustainable forest management." This seems even more surprising considering that the negotiation process was institutionalized at an early stage with the involvement and support of several international agencies. The issue was negotiated over two decades and the UN provided several sub-institutions which provided resources to involve in serious and meaningful deliberations on international forest protection. Therefore, the circumstances under which multilateral forest protection has been discussed were rather favorable. The issue did not just quietly disappear from the international agenda, nor was it intentionally liquidated by its opponents. It is continuously discussed in an international forum that was designed for the sole purpose of elaborating policy options for international forest protection. Nevertheless, ever since the first attempt to put international forest protection on the international agenda in 1992, states refused to produce a legally binding multilateral agreement.

Early efforts on multilateral cooperation aimed at standardizing research methods and assessments procedures. This fits the expectations from the theoretical argument which states that countries call for coordinated research when both costs and benefits are uncertain. However, the argument furthermore states that regime formation becomes more likely if costs are low and benefits are uncertain. This part of the argument is to be tested in the next sections when not only the level of uncertainty, but the actual level of individual costs and vulnerability are operationalized and the relevant data is acquired.

5.4.6 Costs, Benefits and Uncertainties of International Forest Protection

It has been argued that the main rationale for installing international regulation against deforestation is averting global climate change. National deforestation can cause a rise in global temperatures since forests contain and sequestrate large amounts of carbon and filter the greenhouse gas CO_2. But despite a variety of political efforts regarding international forest protection, a legally binding multilateral agreement on this issue is still absent. Therefore, the hypothesis from chapter 3 leads to the expectation that the scientific profile was obstructive and the configuration of costs, benefits and uncertainty turned actors into draggers. According to the hypothesis, if costs were definitely high whereas benefits are uncertain, states anticipate to realize in the best case high benefits at high costs or in the worst case low benefits at high costs. If costs are uncertain while benefits are definitely low, states can anticipate that they will benefit very little at – in the worst case – high costs. The purpose of this subsection is to operationalize costs, benefits and uncertainty for the case of deforestation. This is, in a second step, tested against empirical data.

Costs are conceptualized as direct costs from international regulation. Two economically relevant activities are associated with deforestation: Commercial logging and farmland conversion. Relying exclusively on data on commercial logging would neglect the relevant factor of farmland conversion. Data on farmland conversion, on the other hand, is scarce. A meaningful operationalization, however, has to capture commercial logging *and* farmland conversion. As both activities lead to an increase in CO_2 emissions, this study relies on individual country based data on net CO_2 emissions from forest removal. Emission data, however, does not allow to conclude about the direct economic costs from international regulation, since emission data does not capture the relevance of deforestation for a countries' economy. Therefore, emission data is set in relation to GNP per capita. This has the additional advantage that emission data and GNP is set into relation to the population size of a country to enhance comparability between countries and over time.

The proxy has the merit that, on the one hand, it captures the effects from both deforestation activities and, on the other hand, the proxy is directly related to the negative effects from deforestation. Emission data is obtained from FAOstat (www.faostat.fao.org). The institution calculates CO_2 emissions that directly result from the loss of forest land. Data on GNP/capita is obtained from World Bank statistics. Emissions are measured in gigagrams, GNP is measured in US-Dollar. In some countries, despite commercial logging and farmland conversion, the re-growth of forests dominates deforestation. This is represented by "negative emissions".

Throughout this work, benefits have been conceptualized as "reduced vulnerability". It has been argued in the previous section that climate change has been discussed as the most significant negative transboundary externality from deforestation within international negotiations on forest. Hence, vulnerability is measured through the "Notre Dame Global Adaptation Index" (ND-GAIN). The index combines a range of indicators on exposure, sensitivity and ability to cope with the effects from global climate change and ranks countries from 0 (low vulnerability) to 70 (high vulnerability). However, as outlined in previous sections, the causal chain between deforestation and climate change is rather weak. While it seems scientifically established that deforestation has an effect on global climate change, it remains unclear in which direction the effect yields. The involved scientific uncertainty, therefore, not only concerns the degree to which deforestation might lead to enhanced climate change. Scientific uncertainty rather raises the paradox question whether deforestation could be – at least in some areas – even desirable to abate global climate change[31]. In the light of such fundamental uncertainty, a measure for "vulnerability" rather forms a band that ranges from zero to the individual vulnerability score, since individual climate change vulnerability might not be reduced through the international regulation of global deforestation (see table 5.17). This does not imply that the overall vulnerability of a country can take the value 0, but that their vulnerability to deforestation might take the value 0.

Data is collected for the year 1994 when multilateral discussions on international forest protection were initiated – and for the year 2010 when the so far last negotiation round took place at UNFF. Data for individual states' emissions and climate change vulnerability is presented for 1994 and 2010 in table 5.17.

At first glance, the vast majority of participating countries shared a conducive configuration. This counts for both 1994 and 2010. Only a few changes are observable during the two years. In the light of this data, it seems even more puzzling that participating countries did not reach an international agreement on global forest protection. However, a more detailed look at data as provided in table 5.17 reveals that – despite scientific uncertainty – most states could anticipate that their vulnerability was zero if deforestation did not contribute to climate change or – even if deforestation contributed to climate change – their individual vulnerability was still rather low. A comparison between the two years also reveals that vulnerability decreased over that period of time for most countries (except for Japan and the U.K.).

A more detailed look at data changes the categorization for 1994 and shows that most countries were rather in between than definite pushers. Data also shows

[31] In fact, removing trees from snow-covered surface is repeatedly discussed as an instrument of artificially manipulating the earth's solar budget through – so-called solar radiation management – to employ a "quick fix" for climate change (Shepherd, 2009)

	Net Emissions per GNP/capita		*ND-GAIN-Score*	
Country	**1994**	**2010**	**1994**	**2010**
Australia	0,45	0,55	$0-25$	$0-23$
Brazil	300	26,23	$0-33$	$0-29$
Canada	-0,64	1,73	$0-25$	$0-23$
China	-682	-67,01	$0-36$	$0-30$
Czech Republic	-2,9	-0,63	$0-19$	$0-16$
Denmark	-0,04	0	$0-16$	$0-14$
Finland	-1,5	0	$0-22$	$0-18$
France	-1,3	0,8	$0-16$	$0-15$
India	-158	96,43	$0-49$	$0-42$
Indonesia	400	313,37	$0-36$	$0-33$
Japan	-2,1	-3,34	$0-28$	$0-29$
Malaysia	-74,7	12,37	$0-33$	$0-31$
Mexico	4,82	2,7	$0-32$	$0-29$
New Zealand	-1,43	-0,64	$0-27$	$0-25$
Norway	-0,54	0,3	$0-19$	$0-16$
Russian Federation	47,77	-19,86	$0-31$	$0-28$
Senegal	16,08	5,87	$0-56$	$0-47$
South Africa	-0,88	0	$0-37$	$0-36$
Sweden	-0,07	-0,54	$0-31$	$0-20$
Switzerland	-0,08	-0,04	$0-17$	$0-15$
Turkey	-9,04	-2,86	$0-31$	$0-27$
United Kingdom	0,01	-0,16	$0-15$	$0-16$
United States of America	-13,76	-10,3	$0-21$	$0-19$

TABLE 5.17: Climate Change Vulnerability and Forest Use in 1994 and 2010

that seven countries (Brazil, Malaysia, China, Indonesia, South Africa, India and Senegal) show vulnerability scores that classify them as vulnerable[32]. Among this group, Brazil and Indonesia show high emissions and would therefore face high costs from international regulation, meaning that these two countries have rather an "in between" configuration of high costs and potentially high vulnerability. This leaves a relatively small group of pushers (Senegal, India, South Africa, China and Malaysia).

In 2010, some countries had turned from heavy emitters to mild emitters (Brazil) or even from positive emissions to negative emissions (The Russian Federation). The opposite development is also observable: Countries with negative emissions (China and India) heavily increased their emissions. A comparison between both years shows that – in general – the vulnerability score decreased, meaning that all engaged countries (except Japan and the U.K.) became less vulnerable towards global climate change. This furthermore reduces the group of pushers to South Africa, India and Senegal.

While some of the predicted pushers were actually among the group of supporters (Senegal, South Africa, and Malaysia), China and India do not fit the predictions, as they were categorized as "pushers" according to their emission data and vulnerability score, but actually blocked negotiations. Secondly, while Indonesia's blockage fits the categorization, a shift in Brazil's policy position would have been expected, but is not observable. Countries with an "in between" profile were nearly split evenly among both groups.

5.4.7 Conclusions

The results from the empirical analysis are not easily and clearly interpretable. Retracing the scientific process revealed that in the early 1950s, researchers had trouble to account for the actual amount of forestland and forest loss. This changed as FAO installed an assessment process with a unified definition of forestland,

[32]According to the ND-GAIN methodology, a country that shows a vulnerability score above 33 counts as vulnerable.

standardized processes on how to account for forest land, and data from national official agencies. Though the reliability of FAO data is still under debate, countries were able to compare and assess global forest loss. However, the effects of global forest loss are still scientifically uncertain. One reason for that is the diverse geographic focus of research on forests. Since most research focused *either* on tropical forests *or* on boreal forests, it was impossible to draw general conclusions on the effects of deforestation until the 1990s. The first publications with a broader perspective found that mechanisms are highly interlinked and that it is hard to tell which mechanism dominates, especially since mechanisms vary geographically. Therefore, states still have trouble to assess whether deforestation contributes or slows down global climate change.

At first glance, the hypotheses[33] formulated in chapter 3 offer a straightforward explanation for the stagnation of negotiations: The majority of participating countries anticipated that they would draw only little benefits from an international agreement, even though costs would be low as well. At the same time, a group of countries that is heavily involved economically in deforestation and faces uncertain can be expected to oppose efforts toward regime formation. Hence, the small coalition of pushers were not able to turn the "in between" or "obstructive" configuration of other participating states into a more favorable configuration.

Nevertheless, some aspects cannot be fully explained by the hypotheses. Especially the formation of supporting and opposing coalitions do not match the expectations. Why did countries like India and China that show a clear "pusher" configuration not support a treaty? Why did many countries that show an "in between" configuration shift to either the supporting or the opposing coalition? Why did policy positions of countries like Brazil or China not change, even though their emission patterns changed? Alternative ad-hoc explanations might fill this gap. For example, some supporting states regarded a treaty as an opportunity to

[33] *H 1a: if the profile of scientific uncertainty is conducive, states are more likely to behave as pushers and a regime formation process is more likely to be completed.* H 1b: *if the profile of scientific uncertainty is obstructive, states are more likely to behave as draggers and a regime formation process is more likely to stall.* H 2: *A successful regime formation process is more likely if new scientific knowledge modifies the profile of scientic knowledge towards a pushing profile.*

	Before 1990	*1991– 2000*	*2001 – 2010*
Scientific Process	Difficulties to assess global forest land. Forests were assumed to play a crucial role in carbon cycles and global climate change, but their actual role was still unknown.	First estimates of global forest loss through FAO. Uncertainty whether forests are a net sink or a source for CO_2. First acknowledgement of albedo-effects from deforestation.	Coordinated assessment improved estimates of global forest loss through national inventories. Data reveals (a) a general decline in forest loss and (b) large discrepancies in forest loss between states. Improved understanding of carbon stocks in forests. Uncertainty wether albedo effect overwhelms the CO_2 effect from deforestation on a global level. First attempts to integrate knowledge on carbon cycles, albedo and vaporization into a model to assess the complex interaction of deforestation and global climate change.
Perceived Cost-Benefit-Configuration	Uncertain costs, uncertain benefits	High costs, uncertain benefits	High costs, uncertain benefits
Expected Political Reaction	Call for more research	No international agreement	No international agreement
Observed Political Process	Regionally limited agreements with a focus on trade.	1990: first call for international forest protection. 1994-1995: Commencing multilateral negotiations. Focus on improvements in scientific understanding 1995: Foundation of inter-agency taskforce to organize further negotiations. Repeated meetings and discussions. 1997: Foundation of the International Forest Forum. 2000: Continuing deliberations within the IFF without any substantial outcome.	2005: Proposal of a compensational mechanism for developing countries to mitigate deforestation. 2006-2012: Detailed discussions on compensation program. 2013: Declaration of Warsaw Framework for REDD+, a framework for compensation mechanisms.

Table 5.18: Milestones in Scientific Research and Political Action on Deforestation

resolve some domestic factors. Within the Russian Federation, for example, forest management lies within the legislation of the regional administration (Dimitrov, 2006, :106). An international treaty could shift this in favor of federal legislation. Canada, Malaysia and many European countries hoped that a weak international treaty could fend off domestic pressure for rigid protections or political benefits on other related issues (Dimitrov, 2006, :106). The maneuver to push domestic policies to an international level to gain influential leverage on the issue is observable in other international forums (for example EU politics). Conflicts with other norms, such as free trade, were stressed by the U.S.A., who retrenched their general willingness to support international commitments (Dimitrov, 2006).

Apart form domestic policies, asymmetry and distributional conflicts might explain the stagnation of negotiations. Barrett (2001)'s argument on asymmetry declares that asymmetric states are unlikely to form and international regime, unless asymmetry is resolved through incentives or coercion. The economic and political resources to (using Barrett (2001)'s terms) "buy" cooperation of states that had the strongest interests for international forest protection (Senegal, South Africa, and Malaysia) was rather limited. This is also reflected by the observable discussion on financial compensations. China stated that it would not generally object an internaitonal treaty on forest protection, as long as financial mechanisms were included for its implementation (Dimitrov, 2006, :107). At an IFF-meeting in 2000, a speaker on behalf of developing countries stated that "We do not have a principle objection to a treaty if the money is provided to implement it".

Chapter 6

Findings and Conclusions

> "The idea is like a pair of glasses on our nose through which we see whatever we look at. It never occurs to us to take them off."
>
> Ludwig Wittgenstein *Philosophical Investigations*

This study was motivated by an interest in how international environmental regimes form under the condition of scientific uncertainty. More specifically, this research was motivated by the puzzle why actors form environmental regimes on some environmental issues while they fail to do so on other issues. Literature on environmental regimes explains regime formation either through common (or hegemonic) interests to realize gains from cooperation or through consensually shared knowledge on the issue at stake. This dissertation challenges both views.

Interest-based approaches assume rational actors that maximize their utility according to their pay-off structures. However, on many environmental issues, the underlying basis of knowledge to assess pay-offs from institutionalized cooperation is fragile. How, then, can actors be driven by their individual pay-off structure if they have trouble defining it? Interest-based approaches neglect *scientific uncertainty* as a result of inconclusive or conflicting scientific findings. This limits the applicability of interest-based approaches to a universe of cases without scientific uncertainty, while, at the same time, more and more issues are characterized by scientific uncertainty. Knowledge-based approaches use a concept of uncertainty that is more appropriate to environmental issues. The approaches theorize that consensually shared scientific knowledge drives a regime formation process. They, however, fall short in articulating a consistent theoretical framework. How does knowledge transform into action? This question remains unanswered within knowledge-based approaches.

This dissertation makes three key contributions to the study of international regimes. First, this dissertation offers an innovative theoretical framework which integrates scientific knowledge, scientific uncertainty and individual state interests. Previous research on scientific knowledge and regime formation draws a direct causal link between scientific knowledge and regime formation. This leads to a rather optimistic view on the influence of science and regime formation: A better collaboration among international scientists (epistemic communities) leads to a better scientific understanding of an issue which enhances the chances for successful regime formation (Haas, 1992a). This line of argumentation is, however, problematic in two ways: First, by focussing on the role of epistemic communities, it attributes explanatory power to *agency* (in this case scientists) rather than scientific knowledge (Dimitrov, 2006). Within this theoretical tradition, regime formation is not explained by *scientific knowledge*, but by the behavior of *scientific actors*. Secondly, this argument presumes that an enhanced scientific understanding *automatically* facilitates regime formation. There is no reason to believe that. Advances in scientific knowledge can easily reveal insurmountable obstacles for international cooperation that had not been recognized under scientific uncertainty, or new scientific knowledge can reveal new blank spots in the understanding of an issue.

In contrast to previous research, this study regards science not as a singular independent variable. It is rather argued that the actual *content* of scientific findings shapes individual state interests. This goes beyond Dimitrov (2006)'s suggestion of disaggregating science into different sectors of knowledge. His empirical findings suggest that, for successful regime formation, some sectors of knowledge have to be known with certainty while states tolerate uncertainty on other sectors. However, he does not provide a compelling argument *why* states tolerate uncertainty on some sectors of scientific knowledge, while they are less tolerant towards scientific upon other sectors. This dissertation contributes to closing this gap by arguing that different kinds of knowledge shape different aspects of state interests. In the context of this dissertation, interests have been conceptualized as an aggregate of costs and benefits. It has been argued that the likeliness of regime formation depends on *what* aspect is affected by scientific uncertainty and what aspect is known with certainty. More specifically, the dissertation argues that states are more likely to tolerate uncertainty about possible benefits from cooperation, as long as costs from cooperation remain low. Vice versa, the dissertation argues that states do not form an international regime if costs are uncertain while benefits are low. This leads to the three main hypotheses of this study:

H 1a: If the profile of scientific uncertainty is conducive, states are more likely to behave as 'pushers' and a regime formation process is more likely to be completed.

H 1b: If the profile of scientific uncertainty is obstructive, states are more likely to behave as 'draggers' and a regime formation process is more likely to stall.

H 2: A successful regime formation process is more likely if new scientific knowledge modifies the profile of scientific knowledge towards a pushing profile.

The second major contribution of this dissertation is of conceptual nature. An argument which regards science as a factor that shapes states' interests provides the unique opportunity to test more general arguments on the role of science in politics. Many scholars suggest that scientific ideas influence political action (Adler, 1992; Dimitrov, 2003; Farrell, 2006; Goldstein and Keohane, 1993; Haas, 1992a; Holtham and Hughes Hallett, 1987; Lieberman, 2002; Mitchell, 2006; Parsons, 2002). Investigating shifts in the scientific understanding of an issue from a historical perspective allows to observe whether and how there is an influence on political action. If scientific ideas are causally linked to political action, a changing scientific understanding should result in changing political action. Testing this argument through retracing both the scientific process and the political process is the second innovative contribution of this study. This, however, requires a detailed understanding of the scientific process. For that reason, this study has relied on software-aided bibliographic methods to identify the most influential scientific contributions.

Third, in addition to a historical within-case process tracing, the comparative design of this study includes the whole spectrum of the dependent variable (successful *and* unsuccessful regime formations). This allows to draw more generalizable conclusions on regime formation than previous single-n case studies offer. While the advantages of including unsuccessful cases have been outlined by Dimitrov et al. (2007), very few empirical studies have accounted for unsuccessful attempts of regime formation. Examining conditions that lead to *no cooperation* allow to furthermore test previous arguments about conditions that lead to cooperation. Besides fostering our understanding on the factors that hamper regime formation processes, this study contributes additional case studies on failed regime formation and thus enhances our understanding on the *hows and whys* of failed regime formation.

6.1 The Cases – A Summary of Empirical Results

The theoretical argument makes distinct predictions about the conditions under which an international regime forms and under which conditions such a process fails. More specifically, the theoretical argument predicts that a specific occurrence of the independent variable (configuration of scientific knowledge) leads to a specific occurrence of the dependent variable (regime formation process). The analysis of this study aims at testing whether the theoretical predictions can be observed in real world cases. The results of the analysis are briefly summarized in this section.

6.1.1 Case A: International Regulation of Persistent Organic Pollutants (POPs)

The development of scientific knowledge on POPs can be divided into four phases. The first phase begins with the industrialized production and large- scale use of POPs (before 1960). The second phase between 1960 and 1985 is marked by publications on possible negative effects of POPs. During the third phase (between 1986 and 1995), atmospheric transboundary migration of POPs had been discovered. Between 1996 and 2005, scientific knowledge on transboundary migration patterns advanced.

As summarized in table 6.1, the independent variable in the POPs-case (configuration of scientific knowledge) has changed from a configuration where states had no rationale to engage in international regulation, to a configuration that was conducive in terms of international coordination of research, to a profile that facilitated international regulation of POPs. The theoretical argument therefore predicts for the first phase no political action on the international level. The argument predicts efforts to cooperate at an international level on research during the second phase, and it predicts an international regime to form for the third and fourth phase. As the summary shows, the political process followed the theoretical predictions. No political action on the international level was observable in the first phase. During the second phase, we can observe how states institutionalized the exchange of research efforts internationally. This also fits the theoretical predictions. However, there is a deviation between theoretical predictions and observation for the third face: While the configuration of scientific knowledge had already been conducive during that period, no international regime had been formed. This, however, simply represents a time-lag between scientific findings and political reaction.

The case of POPs is of special informative value for the argument. First, it demonstrates the ambivalent role of new scientific findings. While during the first phase (before 1960) the scientific basis for POPs seemed to be established knowledge, new scientific findings scrutinized previous believes on POPs between 1960 and

	Before 1960	1960 – 1985	1986 – 1995	1996 – 2006
Independent Variable	Strongly obstructive	Conducive for the coordination of research	Conducive	Conducive
Theoretical Prediction	No regime	'Research regime'	Regime	Regime
Dependent Variable	No regime	Coordination of research	No regime	Regime

Table 6.1: Summary of Theoretical Expectations and Empirical Observations on POPs

"Independent Variable" summarizes the occurrence of the independent variable (scientific knowledge) according to empirical observations. This leads to *Theoretical Prediction* on how the dependent variable is expected to occur if the theoretical argument holds true. *"Dependent Variable"* refers to empirical observations on the dependent variable (regime formation).

1985. New scientific knowledge did not reduce scientific uncertainty. On the contrary, new scientific findings increased scientific uncertainty. It has been argued from a theoretical point of view how cognitivist assumptions about new scientific knowledge are debatable. The empirical findings on the POPs case further fuel this doubt.

Secondly, the case of POPs regulation is informative, since it confirms the hypotheses of a general link between the configuration of scientific knowledge and regime formation. No POPs regime had been formed under a configuration that was not conducive. The case also confirms the hypothesis about the impact of changing knowledge and regime formation. In particular, the effect of changing knowledge is observable when new knowledge about transboundary migration patterns of POPs have put the issue on the international agenda. A change of scientific knowledge had triggered political action and had caused political decision makers to actively push for international regulation.

However, the results of this case study have to be taken with some caution. The theoretical argument predicts that political action results from *scientific knowledge* that had changed the cost-benefit-configuration into a more conducive one. Nevertheless, the analysis shows that scientific knowledge was not the only factor that had an influence on the cost-benefit-configuration of states on the international level. While scientific knowledge had triggered political action on the domestic level, as well as the international level, costs form international regulation had decreased through political legislation on the domestic level prior to initiatives on the international level. Additionally, the process-tracing of the scientific process has shown how some POPs (especially pesticides) became more and more ineffective and therefore forfeited some of their economic value. Both mechanisms tend to rival with the hypotheses of the theoretical argument and will be addressed in greater detail in section 6.3.

6.1.2 Case B: The Regime on the Protection of the Stratospheric Ozone Layer

The case of stratospheric ozone depletion can be analytically divided into three phases. Ozone depletion had been a concern between 1960 and 1972, but it had not been associated with CFCs. This changed between 1974 and 1984 when researchers had modeled CFCs induced ozone depletion. This knowledge had become more and more consolidated in the third phase after 1986.

The summary in table 6.2 shows that states have had only little incentive to internationally regulate CFCs-emission between 1960 and 1972, since CFCs had not been considered to be connected with stratospheric ozone. In this case, the theoretical argument predicts no political action at the international level, since the main rationale for institutionalized cooperation – a transboundary dimension of CFCs emissions – had not (yet) been discovered. The scientific understanding of the issue changed after 1973, when CFCs had been found to be a potential cause for a so far modeled, but not yet not measured, ozone depletion. It was quickly realized that replacing aerosol CFCs was rather cost efficient, while replacing non-aerosol CFCs was not. In the light of the argument, this implies that during said time period, the configuration of scientific knowledge had changed to a conducive one for aerosol CFCs, while it remained not conducive for other CFCs. Therefore, the theoretical argument predicts that states were likely to form an international regime to regulate aerosol CFCs, while they would hesitate to form an international regime on other CFCs. After 1986 – the third period – advances in scientific knowledge showed ways to substitute non-aerosol CFCs as well. During the same time period, knowledge on benefits from reducing CFCs emissions advanced and the configuration changed to a strongly conducive configuration. Therefore, since the anticipated costs for reducing CFCs emissions had decreased and benefits from international regulation became more obvious, the theoretical argument predicts that states form an international regime to reduce CFCs emissions.

Retracing the political process (dependent variable) shows that – as predicted by theory – states did not take international action before scientific knowledge suggested a link between CFCs emissions and ozone depletion. The first political reactions are observable after 1974, the year the hypothesis on CFCs emissions and ozone depletion was published. Some states began quickly to domestically regulate the aerosol use of CFCs. Nevertheless, states did not take legal action on an international level to regulate aerosol CFCs. This seems puzzling, since some factors facilitated international regulation on aerosol CFCs: First of all, states that had already implemented domestic regulations can be expected to push for international regulation to avert comparative disadvantages. And, in fact, several initiatives for international regulation by countries that had already regulated aerosol CFCs are observable (Parson, 2003, :41). However, the initiatives failed to overcome resistance by other countries, even though opposing countries showed *a similiar* conducive cost-benefit-configuration. Secondly, cost-efficient substitutes had already been developed, which decreased potential costs from international regulation on aerosol CFCs. Therefore, the theoretical argument has trouble to explain the 'non regime' on aerosol CFCs during the phase between 1974 and 1985.[1]

While emissions of neither aerosol CFCs nor non-aerosol CFCs were regulated sufficiently at an international level between 1974 and 1985, countries have negotiated and signed the 'Vienna Convention', an agreement with little commitments to emission cuts, but with commitment regarding the continuation of the political process and with commitments to exchange scientific information on CFCs and

[1] Parson (2003) offers an explanation by stating that the initiatives lacked institutionalization, continuity and connections to international agencies (Parson, 2003, :43).

	1960 – 1973	**1974 – 1985**	**After 1986**
Independent Variable	–	Not conducive for non-aerosol uses, conducive for aerosol uses	Strongly conducive for all CFCs
Theoretical Prediction	'Research Regime'	Regime for aerosol CFCs, no regime for other CFCs	Regime for all uses
Dependent Variable	Coordination of research	No regime	Regime

Table 6.2: Summary of Theoretical Expectations and Empirical Observations on CFCs
"Independent Variable" summarizes the occurrence of the independent variable (scientific knowledge) according to empirical observations. This leads to *Theoretical Predictions* on how the dependent variable is expected to occur if the theoretical argument holds. *"Dependent Variable"* refers to empirical observations on the dependent variable (regime formation)

stratospheric ozone. The Vienna Convention can therefore be regarded as a regime on international research cooperation. This is surprising in the light of the argument, since the argument predicts international regulations (at least for aerosol CFCs) with regard to the conducive configuration. However, retracing the actual negotiation process shows that the level of knowledge differed across actors *despite* a publicly accessible, internationalized body of scientific research. The negotiation process towards the Vienna Convention shows how some delegates had a very poor understanding of the issue. This explains why states opted for cooperation on research rather then cutting CFCs emissions.

After 1986, political action moved towards the 'Montreal Protocol', which regulated all uses of CFCs. This corresponds with theoretical predictions. During that time period, research on CFCs had shown that (a) substitutes for CFCs were available for all uses of CFCs and (b) to what extent CFCs had to be cut to sufficiently avert negative costs from regulation. Hence, at this point, scientific uncertainty had been reduced and states were able to anticipate how they could realize benefits through a multilateral agreement on CFCs. This turned the configuration into a conducive one and – as expected by the theoretical argument – states formed an international regime to collectively reduce CFCs emissions.

Even though many empirical observations on the case fit predictions by the theoretical argument, the results have, yet again, to be taken with some caution. Similar to the case of POPs, some states had implemented domestic regulation on aerosol CFCs before they engaged in international politics. Among those were the biggest producers of aerosol CFCs and the analysis shows that these states were the strongest pushers for international regulation. Therefore, a decrease of costs from international regulation has depended on previous national legislation rather than changes in the scientific understanding of aerosol CFCs. This furthermore raises the question of domestic policy making under scientific uncertainty.

Additionally, the case also shows how scientific knowledge "does not speak for itself". Knowledge on substitutes for non-aerosol CFCs had been announced as early as 1980 by the CFCs industry, but the message has been widely misunderstood. In 1986, the same information had been presented by industry representatives, but it was anticipated very differently by political decision makers. At this point, the message that came across was that all CFCs could be replaced in a cost-efficient manner (Parson, 2003). Whether business representatives had strategically framed scientific facts in their favor or whether political decision makers just had too little general knowledge on CFCs to comprehend the information in 1980 could not be clarified in this study. However, the story shows that the way scientific knowledge influences cost-benefit-configurations does not only depend on what information is available, but how it is perceived by decision makers.

6.1.3 Case C: The Non-Regime on Arctic Haze

The case of Arctic haze has been divided into four different phases. While the phenomenon of Arctic haze had been known since the early 1950s, it did not attract much attention before 1975. Between 1975 and 1981, research intensified and focused on a potential link between Arctic haze and soil acidification. Black carbon, sources and migration patterns dominated the scientific debate between

1981 and 1990. The thermal effects of black carbon in the Arctic occupied researchers between 1991 and 2001. The debate was integrated into the discussion on short-lived climate forcers after 2001.

As summarized in table 6.3, scientific knowledge did not indicate the need for political action regarding the issue during the first phase, since there was no reason to assume anthropogenic sources of Arctic haze. Therefore, the theoretical argument predicts no political action to reduce Arctic haze. During the second phase between 1975 and 1981, research showed that Arctic haze was an anthropogenic phenomenon. However, many issues to determine costs and benefits from collectively reducing Arctic haze were still highly uncertain. Consequently, the theoretical argument predicts that states would be likely to institutionalize cooperation on research to benefit from enhancing knowledge. The configuration remained non-conducive between 1991 and 2000, since costs were regarded to be high while benefits were highly uncertain. Therefore, the theoretical argument expects no regime formation. After 2001, scientific knowledge on the effects of Arctic haze improved. New findings suggested that Arctic haze would, in fact, exhilarate global climate change. Therefore, the theoretical argument predicts that a regime formation that contains legally binding commitments on emission cuts of black carbon is unlikely.

As expected by theoretical predictions, Arctic haze has not been a political issue during the first phase before 1975. But the theoretical argument predicted that states would begin to intensify and internationally coordinate their research after the anthropogenic nature of Arctic haze had been discovered and after several negative effects had been associated with it. This is, however, not observable during the second and third phase. In the third phase after 1991, states signed the Arctic Environmental Protection Strategy and founded the Arctic Council in 1996 as a diplomatic forum to enhance cooperation on the Arctic environment. While the political output of the Arctic Council is rather small, it has installed a very productive research institution (AMAP), which has published research results on Arctic haze. Since the mandate of the Arctic Council is primarily science-oriented, it can be regarded as a research regime. Though an earlier formation of a research

	Before 1975	**1975–1981**	**1981–1990**	**1991–2000**	**2001–2010**	**After 2010**
Independent Variable	–	Not conducive	Conducive for the coordination of research	Not conducive	Not conducive	Not conducive
Theoretical Prediction		Research Regime	Research Regime	No Regime	No Regime	No Regime
Dependent Variable	No Regime	No Regime	No Regime	Research Regime	No Regime	No Regime

Table 6.3: Summary of Theoretical Expectations and Empirical Observations on Arctic Haze
"Independent Variable" summarizes the occurrence of the independent variable (scientific knowledge) according to empirical observations. This leads to *Theoretical Predictions* on how the dependent variable is expected to occur if the theoretical argument holds true. *"Dependent Variable"* refers to empirical observations on the dependent variable (regime formation).

regime has been predicted by the theoretical argument, it can be argued that this is just a time-lag. During the last phase after 2001, no efforts to cuts black carbon emissions are observable within the Arctic Council. However, changes in the diplomatic language are observable. With the Nuuk declaration of 2011, states have acknowledged the issue of Arctic haze and its significance for the global climate and committed to take further action on the issue.

In the light of theoretical predictions and empirical observations, the case supports the hypotheses. Furthermore, the case is a perfect example for the very different policy implications that can be derived from different models. Especially before the year 2006, two rivaling explanatory models on the effect of Arctic haze concluding very oppositional effects. To mitigate climate change, one model has called for a reduction of Arctic haze, while the other model called for the opposite action.

6.1.4 Case D: The Non-Regime on International Forest Protection

The developments on global deforestation have been divided into three phases. Before 1990, researchers assumed that forests played a crucial role in the global carbon cycle, but struggled to exactly clarify its role and struggled to assess the extent of global deforestation. During the second period between 1991 and 2000, estimating the extent of global deforestation was facilitated by technological advancements. However, the actual effects on climate remained uncertain. While national inventories of deforestation made assessments on global deforestation even more precise between 2001 and 2010, two oppositional mechanisms aggravated the assessment of effects from deforestation.

Table 6.4 shows a configuration under which the theoretical argument predicts that states coordinate their research efforts in a research regime during the first phase (before 1990). During the second phase (1991 – 2000) costs have been perceived as high and benefits were uncertain. Consequently, the theoretical argument predicts no regime to form during this period of time. Knowledge on the extent of deforestation has been enhanced between 2001 and 2010 to a high level of accuracy. However, the complex relationship between CO_2, albedo and vaporization made it difficult to assess actual benefits from regulating global deforestation. Therefore, since benefits remained uncertain while costs from regulating deforestation remained high, the theoretical argument predicts no regime formation.

In contrast to theoretical predictions, states did not form an explicit research regime on global deforestation during the first phase. However, FAO had been mandated to collect data and had published assessment reports on both extent and effects of global deforestation. Even though the issue of regulating global deforestation had been considered at an international level during the second phase (between 1991 and 2000), no regime that explicitly regulates global deforestation has been formed. The issue was debated within different international forums and agencies to assess the need for international regulation. Even though this process of scientific assessment and political deliberation continued over years, it produced only very little substantial political output beyond declarations of intent. Repeated declarations of intent without substantial political output continued over the third period, and no regime had been formed.

In the light of the argument, political action generally fits theoretical predictions.

	Before 1990	**1991 – 2000**	**2001 – 2010**
Independent Variable	Conducive for the coordination of research	Not conducive	Not conducive
Theoretical Prediction	'Research Regime'	No Regime	No Regime
Dependent Variable	No Regime	No Regime	No Regime

Table 6.4: Summary of Theoretical Expectations and Empirical Observations on Deforestation
"Independent Variable" summarizes the occurrence of the independent variable (scientific knowledge) according to empirical observations. This leads to *Theoretical Predictions* on how the dependent variable is expected to occur if the theoretical argument holds true. *"Dependent Variable"* refers to empirical observations on the dependent variable (regime formation).

Even though states did not form a research regime during the predicted time period, it can be argued that FAO served a similar purpose and produced sufficient coordinated assessment reports. A research regime with an explicit focus on international forests would have been obsolete. Additionally, the various initiatives at the international level to protect global forests after 1991 also had a coordinating function and a mandate to enhance the scientific understanding of the issue (see for example: UN.CSD (1995)).

Some aspects of the case, however, cannot be sufficiently explained by the theoretical argument. Most prominently, it seems puzzling why states continued to engage in deliberations for an international regime on forest protection when such discussions frequently failed to produce a political outcome that goes beyond recommendations and declarations of intent. Secondly, the hypotheses emphasizes that states are more likely to become pushers if they face a conducive configuration. The empirical process tracing, however, showed some deviations of the predicted negotiation behavior, meaning that some states that faced a conducive configuration did not support the formation of an international regime, and vice versa. Additionally, policy positions of some states did not change even though a change in the body of scientific knowledge would imply such changes.

6.2 Theoretical Predictions and Empirical Findings Within and Across Cases

The single case analysis has highlighted the developments on the independent variable, as well as the developments on the dependent variable from a historical perspective. One key finding from this perspective is that politics have responded to science and *regime formation has been influenced by scientific knowledge*. The second key finding of the within-case comparison is that *different aspects of scientific knowledge have spurred different kinds of political action*. It has been argued in this study that science changes the perception of highly technical issues which require specialized expertise. It therefore changes the evaluation of policy options. The single-case analysis shows how shifts in political positions have been induced by scientific findings and hence supports this notion.

Both conclusions may seem trivial at first glance. However, the possible link between scientific knowledge and political decision making is still controversial among scholars of international regimes (Andersen, 2000; Haggard, 1987; Martin and Simmons, 1998; Parson, 2003). With regard to this dispute within literature, demonstrating an influence of science on politics and demonstrating how different aspects of scientific knowledge trigger different political actions are necessary steps towards the core argument of this study; to argue that a specific configuration of scientific knowledge leads to a specific cooperative behavior requires credible evidence that scientific knowledge actually influences political decision making at all. Similarly, showing that different aspects of scientific knowledge impact political decision-making differently is a requirement for arguing that a specific configuration of scientific knowledge has an effect on the outcome.

While all four cases support these conclusions to some degree, the case of successful regime formation on Persistent Organic Pollutants and the case of unsuccessful regime formation on Arctic haze are especially suitable for demonstrating the mechanism. Even though both phenomena as such had been known for many years, the issues have not been considered as issues that require political action.

With upcoming knowledge about negative effects, policy-makers felt the need to act. Secondly, both issues have found their way on the international agenda after scientific findings suggested a transboundary dimension. For example, in the beginning, researchers assumed natural or local sources for Arctic haze. But by the time scientific findings indicated far-distant anthropogenic sources and knowledge on long-range transportation accumulated, political decision makers began to approach the issue at an international level. A similar development is observable for the case of POPs, which were assumed to be a local issue before they had been traced in far-off places and their complex transport patterns had been studied. This indicates how changes in science impact political action which gives further confidence in the argument that different aspects of knowledge have different implications for political action.

While the single-case studies have confirmed the theorized link between scientific knowledge and political action, the focus of the comparative perspective lies on the theorized link between a specific configuration of scientific knowledge and the outcome of an initiated regime formation process. The findings of the empirical analysis across cases are summarized in table 6.5. The findings from the cross case comparison are not as easily and clearly interpretable as the single-case studies. Nevertheless, some conclusions can be drawn with confidence. The results indicate that regime formation processes which are marked by a conducive configuration are more likely to result in a successful international regime. This conclusion is based on the observation that both successful cases of regime formation have a conducive configuration in common. However, the successful case of regime formation on stratospheric ozone depletion is nuanced. The configuration of scientific knowledge developed from a profile where both dimensions were uncertain to a conducive profile for the sub-issue of aerosol CFCs and a non-conducive profile for the sub-issue of non-aerosol CFCs. The configuration turned into a strongly conducive configuration when scientific uncertainty was (more or less pragmatically) resolved. Therefore, strictly speaking, with new findings ruling out remaining uncertainties, the last phase of the CFC case actually drops out of the universe of cases for this study. Even though the case shows how changes in scientific findings correspond with changes in policy positions, an argument about how states behave under the condition of scientific uncertainty cannot be tested against the case.

Therefore, the case of POPs is more informative for drawing conclusions on successful regime formation under the condition of scientific uncertainty. The case shows how the configuration shifted from a strongly obstructive configuration to a configuration where both costs and benefits were uncertain. During the last phase, the configuration was transformed into a conducive configuration and states agreed on forming an international regime despite substantial uncertainty about benefits. These shifts are reflected by political action (see section 6.1.1).

The opposite effect – no regime under an obstructive configuration – is harder to track from the comparative perspective due to a lack of empirical observations. This study argues that successful regime formation is unlikely when costs are uncertain and benefits are low. However, within the chosen sample of cases, this *specific* configuration has not been observed. Therefore, it cannot be concluded unambiguously from empirical data that an obstructive configuration as defined in this study leads to a non-regime. Three arguments, however, give reason to still have confidence in the hypothesis. First of all, while the 'uncertain costs/low benefits' configuration has not been observed, there are observations for all other configurations that are captured by the theoretical argument. The majority of observations fit theoretical predictions. In the light of the configurations for which observations are available, it can be concluded that (a) states did not form a regime under obstructive conditions, (b) states only formed regimes under conducive conditions, and (c) states coordinated research efforts under conditions when both dimensions were uncertain. This implicates that, in general, an argument about a link between the configuration of scientific knowledge and regime formation is supported. Thus, it seems plausible to argue (with some caution) that it is unlikely for states to form an international regime under an obstructive costs / uncertain benefits configuration. Secondly, hypothesis 1b (regime formation is unlikely under an obstructive configuration) has not been *disconfirmed* by empirical findings. The hypothesis would have been disconfirmed by empirical evidence if an international regime had been formed *despite* an obstructive configuration.

As table 6.5 shows, this has not been the case in the cases under investigation. Third, even under a configuration that was *less* obstructive than the described configuration, states did not form an international regime. The high costs/uncertain benefits configuration has been described as slightly more conducive than the uncertain benefits/high costs configuration (see table 3.4), since there is a chance for states to realize high benefits (even at high costs). In terms of regime formation, the configuration is not clearly conducive, nor is it clearly obstructive, but it is definitely more conducive than the uncertain costs/low benefits configuration. If states did not form an international regime under a high costs/uncertain benefits configuration, it seems plausible to assume that they would not form an international regime under a configuration that was even less conducive. Even though these arguments partially restore confidence in the argument, it is undeniable that the lack of empirical observations decreases the causal (or internal) validity of this study. Technically speaking, while the analysis confirms a link between "x" (configuration of scientific knowledge) and "y" (likeliness of successful regime formation), the analysis has not been able to confirm that "non-x" leads to "non-y". This does not implicate that the theoretical argument has to be refuted as a whole, which would only be the case if the empirical analysis had shown that "x" also leads to "non-y".

The single case analysis and the comparative perspective have shown what parts of the argument could be *tested* against the empirical data of the selected cases and what parts of the argument have been *confirmed* or *disconfirmed* by empirical evidence. The empirical evidence suggests an influence of scientific knowledge on political decision-making. Furthermore, the analysis has shown how different aspects of scientific knowledge have caused different political reactions. However, while empirical data has shown that states formed international regimes *only* under conducive conditions, lacking observations do not allow to conclude the opposite mechanism of an obstructive configuration leading to a stalling regime formation process. Therefore, while hypothesis 1a and 2 were positively confirmed by this study, hypothesis 1b could be neither confirmed nor disconfirmed. The empirical analysis indicates that scientific knowledge played a causal role in the regime formation process of the analyzed cases. It also indicates – as postulated by the theoretical argument – that the actual content of scientific knowledge has an influence on the likeliness of successful regime formation.

6.3 Alternative Explanations

The cases for this study have been selected to being *as similar as possible* to control for alternative explanations (George and Bennett, 2005; King et al., 1994; Lijphart, 1975). However, even though the formulated selection criteria strengthens similarities across cases, perfect similarity is almost impossible to achieve and rivaling explanations need to be addressed. Even though the empirical analysis confirms (or at least does not contradict) the drawn hypotheses, the results have to be interpreted with some caution, since the observed variance on the dependent variable might be caused by other factors than the theoretical argument suggest. Especially the influence of pre-existing domestic legislation, vested interests from decision makers or interest groups on the scientific process, or an exploitation of scientific uncertainty to pursue individual or national interests could account for success or failure of a regime formation process.

6.3.1 Science and Interests

Throughout this study, the relationship between science and politics has been treated as a one-way street where science informs political decision-makers and scientific findings shape states' interests. However, this relationship could easily work the other way around where scientific findings and the way they are presented are influenced by interests. In this context, at least three mechanisms seem possible. First of all, ambiguity caused by scientific uncertainty can be exploited in different ways. Political decision-makers can hide their 'true' distributional interests behind a "veil of uncertainty" (Helm, 1998) to block international cooperation by referring to uncertain science rather than a state's own self-interest. Scientific

Costs \ Benefits	low	uncertain	high
low	***intermediate***	***likely:*** • POPs III (1986-2005) • POPs IV (1986-2005) • Aerosol CFCs II (1974 - 1985)	***highly likely:*** • CFCs III (After 1985)
uncertain	***unlikely***	***coordination of research efforts:*** • POPs II (1960-1985) • CFCs I (1960-1973) • Arctic Haze II (1975-1981) • Arctic Haze III (1981-1990) • Deforestation I (Before 1990)	***likely:*** • Arctic Haze V (After 2001)
high	***highly unlikely:*** • POPs I (Before 1960) • Arctic Haze I (Before 1975)	***unlikely:*** • Non-aerosol CFCs II (1974-1985) • Arctic Haze IV (1991-2000) • Deforestation II (1991-2000) • Deforestation III (After 2000)	***intermediate***

TABLE 6.5: Empirical Findings on the Likeliness of Regime Formation at Different Historical Phases
Every case is analytically separated into different historical stages (see chapter 5, especially tables 5.10, 5.12, 5.15 and table 5.18) to increase the number of empirical observations (for details, se chapter 4). Each observation has been assigned to a specific cost-benefit-configuration and its likeliness for regime formation.

uncertainty also allows political decision-makers to pick scientific findings that speak in their favor to leverage their bargaining position.

Scientific uncertainty may facilitate the exertion of political power. In the 'post-structuralist' tradition, researchers have analyzed how knowledge is shaped by power and how it reproduces power (Dillon, 2013; Foucault, 2008; Gramsci, 1980). In this tradition, knowledge is perceived as a socially constructed phenomenon and is as such prone to being shaped by social factors. Researchers from natural science would probably deny an influence of social factors on the 'hard facts' of physics, math and chemistry. However, studies have shown that the *interpretation* of scientific knowledge can indeed be influenced by power through a 'prerogative of interpretation' (Blaikie, 1995; Oels, 2005; Wiertz, 2011). In the light of scientific uncertainty, the range of possible interpretations generally becomes wider, which offers the opportunity for actors to exert their power and to shape interpretations of scientific findings in their favor. For this study, this means that the configuration of costs and benefits was not *purely* science-based, but depended on how (powerful) actors interpreted scientific findings.

Within a more positivist fashion, researchers have investigated the mechanisms through which politics controls the production and transmission of scientific knowledge (Clark, 2001; Lidskog and Sundqvist, 2002). To the largest extent, researchers depend on politically controlled funding. Evidently, this can be a means to exert influence on science and to shape scientific findings in one's favor (Hegde, 2009). For this study this would mean that political decision makers *primarily* funded research projects from which they could expect to produce findings that correlate with their interests.

The focus in this chapter has been on how political interests may shape science. However, within the nexus of science and politics, political actors are not the only stakeholders. Scientists and scientific institutions do not carry out research in complete independence. As Underdal (2000) puts it, "There is no reason to believe that the production of knowledge should be the only productive activity in society that does not generate its own stakes for those involved." (Underdal, 2000, :5). As the producers of knowledge, scientists and scientific institutions depend on funding and have to consider individual career paths. This does not necessarily imply that researchers or research institutions deliberately bias their research in favor of a certain outcome. However, actors in the scientific domain have an interest in what topics make it on the scientific agenda and what topics stay on the agenda (Boehmer-Christiansen, 1997). In environmental politics, the most effective way to acquire funding for further research is to portray an issue as potential threat (thus emphasizing the relevance of the issue) and at the same time as highly uncertain (thus justifying the need for publicly funded research). Through this mechanism, scientific institutions may overstate scientific uncertainty to secure future funding[2]. This, of course, presumes at least some political control over mainly publicly funded research institutions. In the light of this research, this would mean researchers deliberately miss-communicate scientific findings to political decision-makers in order to keep an issue on the political and scientific agenda.

These considerations have shown how interests of political decision-makers can bias scientific findings. While theoretically convincing, this thread of argumentation neglects the *true nature* of scientific uncertainty. It has been argued that scientific uncertainty prohibits the formulation of clear-cut utilities for states. Therefore, even if decision-makers *wanted* to influence scientific findings, they would not know in which direction to bias findings. It therefore seems implausible that political interests are better suitable to explain the outcome of the dependent variable. However, the considerations also argue that scientific actors influence the process of knowledge-production. This presumes that scientific actors have a bigger interest in retaining funding than in solving a potential environmental policy dilemma. The analysis of the CFC case has shown that this can especially be the case in privately funded research where industry-sponsered researchers deliberately emphasized scientific uncertainty for economic reasons. The same case study has shown an opposite effect where scientific actors deliberately underscored scientific

[2]This mechanism has empirically been investigated by Boehmer-Christiansen (1997).

uncertainty to influence policy decisions. This shows how scientific actors can exploit their prerogative of knowledge.

6.3.2 Compliance and the Choice of Policy Instruments

This study takes a rather simplistic view on regime formation. It merely focuses on the formal aspect of regime formation and neglects the actual content of the negotiation agenda. However, there is an argument that over what policy makers are bargaining about influences the outcome of whether a regime is formed or not. Between "business as usual" and "immediate emission reduction to zero", there is a whole range of possible policy instruments, such as emission caps, emission reduction to a certain threshold, phase-out, stop in production, stop of usage, stop of trade, and so on. Different policy instruments have different implications in terms of costs and benefits and may thus have an impact on states' willingness to form an international regime (Koremenos et al., 2001). The comparative perspective of this study can, however, weaken causal claims of this alternative explanation. If the choice of policy instruments had decisive influence on success or failure of regime formation, negotiated policy instruments in both successful cases should be similar. Vice versa, policy instruments in both unsuccessful cases of regime formation should be similar. However, the analysis of the successful regime formation processes shows that both regimes installed different policy instruments. While the Montreal Protocol obligates states to cut production, use and trade of CFCs (Parson, 2003, :145), the LRTAP Protocol on POPs showed more flexibility in the form of phase-outs and compromises on time-lines (Selin, 2000). Nevertheless, the empirical analysis of both cases has also shown that the choice of the appropriate policy instrument was a matter of discussion during negotiations. Therefore, a general influence of policy instruments cannot be ruled out and the issue remains on the research agenda for regime study.

A similar argument can be made about compliance mechanisms that are integrated in an international regime. Since it has been argued in the theoretical argument that one motive for forming an international regime is to ensure compliance, it can be theorized that the weaker the compliance mechanisms are, the more likely states will agree to forming a regime. This follows the argument of "cheap talk" or cheap diplomacy (Ramsay, 2011). However, the case of CFCs gives reason to doubt this argument. The Montreal Protocol has broad membership, explicit emission targets and a variety of mechanisms to ensure compliance, reaching from technical assistance to warnings and even suspension from the treaty (Barratt-Brown, 1991). Following an argument based on compliance, the Montreal Protocol would seem implausible.

6.3.3 Domestic Politics

The dissertation follows a rather new and complex theoretical argument, which was tested against four empirical cases from a historical perspective. The arguments for a comparative case study that employs process tracing (see section 4.1) instead of employing a more commonly used in regime analysis are convincingly strong. However, for reasons of feasibility, this type of research design requires a narrow scope. Therefore, the empirical analysis almost exclusively considers political action on the international level and neglects the domestic level in great part. There is, however, a strong argument that regime formation is facilitated by preexisting domestic legislation. Bottom up norm creation did so far not draw too much attention within the study of international relations, but became a topic in the study of international law (Levit, 2005). There are several reasons to attribute alternative explanatory power to pre-existing domestic regulation.

First of all, pre-existing national legislation indicates that an issues has already been recognized as an issue that deserves political reaction of some form. If states have already installed legislation on the domestic level, the question on the international level becomes a question of *how* to regulate it rather than *whether* to regulate or not. Even if knowledge on a transboundary dimension was uncertain, states would have an incentive to push for international regime formation to level possible comparative (dis)advantages of non-regulating states. And in fact, the empirical analysis shows that pre-existing domestic legislation which decreased costs from international regulation is observable in both successful regime formation processes while no issue-specific domestic legislation is observable in the two regime formation processes that failed or stalled. It might therefore be possible that preexisting national legislation might have more explanatory power than the configuration of scientific knowledge. This points to the question of domestic law-making under the condition of scientific uncertainty. If pre-existing domestic legislation has an impact on international regime formation, the more relevant question to ask would be how scientific uncertainty influences national norm creation. It can be speculated how scientific uncertainty can more easily be exploited by interest groups, such as NGOs or industry branches. For example, in both successful cases of regime formation (POPs and stratospheric ozone) we can observe strong engagement of civil society through NGOs or the media and in both cases, a bias towards regulation *despite* scientific uncertainty is observable on the domestic level. This mechanism certainly is a field for future policy analysis.

6.3.4 Evaluations

Some of the above mentioned alternative explanations are mitigated through the methodological architecture of this study. Even though it was observable that political decision-makers underpinned their policy positions with different scientific findings, there is no evidence that policy makers have concealed their "true" interests and exploited scientific uncertainty. This ties in with an argument that has been already made in chapter 3: In the light of scientific uncertainty where states (initially) not know if they gain or loose from institutionalized cooperation, how can they determine their own interests? Consequentially, how can they pick scientific findings that speak in their favor? A similar argument counts for a possible manipulation or filtering of scientific findings. Even if political decision-makers intended to exert influence on how science is produced and communicated, how should they decide what scientific results are favorable for their interests if scientific uncertainty prohibits the articulation of unambiguous pay-offs? For example, in the light of conflicting models on the effects of Arctic haze, how should decision-makers have decided on which model to prefer? In the context of this study, it seems therefore implausible to assume that the interests of states shaped scientific findings in the cases under investigation. This is reflected by the case-studies, which do not imply that such a mechanism was at work.

A similar argument can be made about the exertion of power. If international regimes were only epiphenomenal, hegemonic states have to have an idea in which direction they need to exert their hegemonic power. Additionally, the absence of a clear hegemonic states during the time-span speaks against a power-based explanation for success and failure of regime formation. It can be argued that the U.S.A. might not have been a hegemonic state, but a state with sufficient means of power to direct a regime formation process towards a certain direction. However, empirical evidence collected in this study does not support this notion. For example, regime formation on deforestation was heavily pushed by the U.S.A., but was blocked by developing countries (Dimitrov, 2006, :161). Therefore, uncertain pay-offs and empirical evidence weaken the explanatory leverage of power. While it is certainly plausible that the content of possible policy options has an influence on the outcome of regime negotiations, the dissimilarities between policy instruments across cases that show *the same* outcome speak against this alternative explanation.

The strongest rivaling alternative explanation remains pre-existing domestic policy. From a theoretical point of view, it seems intuitive that states are more inclined to form an international regime on issues that they have already regulated themselves. Empirically, this view is partially supported from the comparative perspective. The majority of involved states has already implemented some form of domestic policy to regulate POPs and CFCs. This has not been the case with Arctic haze and global deforestation. The formation of public opinion on issues that are marked by scientific uncertainty and its effect on national and international norm creation are an urgent research agenda that deserves further attention. While the empirical analysis confirms the hypotheses in general, the possible effect from domestic policy needs to be studied to consolidate or scrutinize the results of this study.

6.4 Implications for Research, Policy and International Law

This study has confirmed and strengthened conclusions from previous research on a causal relationship between science and politics. However, this study has also shown that this relationship seems to be more sophisticated than it has been assumed by previous research. This work has focused on the puzzle why states form environmental regimes on some issue while they fail on other issues. The theoretical and empirical evidence implies that shortcomings in explaining this puzzle are partially caused by a too simplified concept of either *knowledge* or *interests*. This means for researchers on international regimes that considerations on what was known at what point in time and what this knowledge implied for political action offers explanatory power to this puzzle.

These implications are, however, not exclusively reserved for the formation of international environmental regimes. The implications can easily be transferred to other fields of policy-making, either on a national or an international level. Put simply, scientific uncertainty in international environmental policy has been pictured as a situation where different plausible scientific models predict different outcomes from political action. This phenomenon can be found in many other fields as well. Agricultural politics, central bank decisions and macroeconomic policy are only some of the many fields that come to mind which are possibly prone to scientific uncertainty. Introducing scientific uncertainty into the research on this field offers a more detailed view on factors that influence cooperative behavior through international institutions.

This has important implications for policy-making. The ignorance of scientific uncertainty can lead to suboptimal policy choices. Unfortunatly, there is no suitable "rule of thumb" on how to do politics under scientific uncertainty. The often hailed and praised *precautionary principle*[3], for example, has to be considered with caution. The principle calls for political action *despite* scientific uncertainty. However, the empirical analysis has shown that political action in the light of scientific uncertainty could lead to the opposite of the intended outcome. This is illustrated in particular by the case of Arctic haze, where the precautionary principle could have been referred to in order to increase black carbon emissions at an early stage of research.

Newly emerging issues of global governance, such as climate engineering, face a similar dilemma. This emerging technology is designed to avert increasing temperatures from climate change, but it is burdened with high scientific uncertainty about unintended side-effects. Possible side-effects may comprise unwanted responses from nature, such as changes in precipitation patterns, as well as unwanted social responses, such as a further delay of CO_2 emission cuts (Shepherd, 2009). In the light of increasing average temperatures, the precautionary principle tends to argue in favor of the implementation of climate engineering measures. However, the technology itself could cause damages comparable to possible damages from climate change.

These examples show a dilemma which is hard to resolve. On the one hand, delaying political choices could lead to negative environmental effects that might even be irreversible. On the other hand, insufficiently informed policy choices could lead to a situation that leaves stakeholders in a similar or even worse situation, in terms of irreversible environmental effects. It is therefore advisable for policy-makers to consider scientific findings and their implications more closely before deciding on issues that are still marked by scientific uncertainty. More specifically, decision-makers should be aware of the tentativeness of scientific research on

[3]Principle 15, Rio Declaration of the United Nations: *"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."*

complex systems and take into consideration that the current state of knowledge might be misleading.

6.5 Agenda for Future Research

This research has demonstrated how scientific knowledge can change the perspective of policymakers on an issue. Moreover, it revealed three areas where future research seems most promising. The most urgent area has already been mentioned: A further investigation of additional environmental regimes is certainly fruitful to see if the argument is confirmed by other cases than the selected ones. Furthermore, additional data on the mechanism on how scientific findings shape state interests would increase the robustness of the findings. Especially data on the perception of stakeholders from science and from politics seems fruitful to further investigate whether the suggested mechanism is at work. This would contribute to answering the question on how knowledge is transformed into action.

Secondly, this study has built upon the still standing research agenda on failed attempts of regime formation. Dimitrov et al. (2007) offer convincing arguments why a focus on failure offers additional insights for regime study in general. This study offers additional explanations for the failure of regime formation. However, much work is still to be done in conceptualizing failed regime formation to more easily identify failed regime formation attempts.

Third, while regime study has progressed over decades now, it would profit from a shift from single case studies or small-n comparative case studies towards a more comprehensive comparative perspective. The international regime data base (Breitmeier et al., 2006) is a good start into the right direction and should be pursued by the field. This would also allow to test the interplay between some hypothesized variables more carefully.

Bibliography

Abbott, D., Harrison, R., Tatton, J., Thomson, J., 1965. Organochlorine pesticides in the atmospheric environment. Nature 208 (5017), 1317–1319.

Abbott, K. W., Snidal, D., 1998. Why states act through formal international organizations. Journal of Conflict Resolution 42 (1), 3–32.

Achard, F., Eva, H. D., Stibig, H.-J., Mayaux, P., Gallego, J., Richards, T., Malingreau, J.-P., 2002. Determination of deforestation rates of the world's humid tropical forests. Science 297 (5583), 999–1002.

Adler, E., 1992. The emergence of cooperation: national epistemic communities and the international evolution of the idea of nuclear arms control. International Organization 46 (1), 101–145.

Advisory Committee on Poisonous Substances used in Agriculture and Food Storage, 1964. Review of organo-chlorine pesticides. Tech. rep., Advisory Committee on Poisonous Substances used in Agriculture and Food Storage.

Alavanja, M. C., Samanic, C., Dosemeci, M., Lubin, J., Tarone, R., Lynch, C. F., Knott, C., Thomas, K., Hoppin, J. A., Barker, J., et al., 2003. Use of agricultural pesticides and prostate cancer risk in the agricultural health study cohort. American Journal of Epidemiology 157 (9), 800–814.

Allen, J., Norback, D., 1973. Polychlorinated biphenyl-and triphenyl-induced gastric mucosal hyperplasia in primates. Science 179 (4072), 498–499.

Alt, J. E., Calvert, R. L., Humes, B. D., 1988. Reputation and hegemonic stability: A game-theoretic analysis. The American Political Science Review, 445–466.

AMAP, 2006. Arctic pollution 2006: Acidification and Arctic haze. Tech. rep., Arctic Monotoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP, 2011. Technical report on the impact of black carbon on Arctic climate. Tech. rep., Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

Andersen, S., 2000. The whaling regime. In: Steinar Andresen Tora Skodvin, A. U. J. W. (Ed.), Science and Politics in International Environmental Regimes. Manchester University Press: Manchester, pp. 35–70.

Andreae, M. O., 2001. The dark side of aerosols. Nature 409 (6821), 671–672.

Arctic Council, 1991. Arctic environmental protection strategy.
URL http://www.arctic-council.org/index.php/en/document-archive/category/556-arctic-environmental-protection-strategy

Arctic Council, 2012. Agreement on cooperation on marine oil pollution.
URL http://www.arctic-council.org/index.php/en/document-archive/category/556-arctic-environmental-protection-strategy

Arrebola, J. P., Fernandez, M. F., Porta, M., Rosell, J., de la Ossa, R. M., Olea, N., Martin-Olmedo, P., 2010. Multivariate models to predict human adipose tissue PCB concentrations in southern spain. Environment International 36 (7), 705–713.

Atkinson, R., Baulch, D., Cox, B., Hampson Jr, R., Kerr, J., Troe, J., 1989. towards a quantitative understanding of atmospheric ozone. Planetary and Space Science 37 (12), 1605–1620.

Austin, J., 1980. The blocking of middle latitude westerly winds by planetary waves. Quarterly Journal of the Royal Meteorological Society 106 (448), 327–350.

Axelrod, R., Hamilton, W. D., 1984. The evolution of cooperation. Science 211 (4489), 1390–1396.

Bahn, A. K., Rosenwaike, I., Hermann, N., Grover, P., Stellman, J., O'Leary, K., 1976. Letter: Melanoma after exposure to PCB's. The New England Journal of Medicine 295 (8), 450.

Baker, E., Landrigan, P., Glueck, C., Zack, M., Liffle, J., Burse, V., Housworth, W., Needham, L., 1980. Metabolic consequences of exposure to polychlorinated-biphenyls (PCB) in sewage-sludge. American Journal of Epidemiology 112 (4), 553–563.

Bala, G., Caldeira, K., Wickett, M., Phillips, T., Lobell, D., Delire, C., Mirin, A., 2007. Combined climate and carbon-cycle effects of large-scale deforestation. Proceedings of the National Academy of Sciences 104 (16), 6550–6555.

Barratt-Brown, E. P., 1991. Building a monitoring and compliance regime under the montreal protocol. Yale Journal of International Law 16, 519.

Barrett, S., 1994. Self-enforcing international environmental agreements. Oxford Economic Papers 46, 878–894.

Barrett, S., 2001. International cooperation for sale. European Economic Review 45 (10), 1835–1850.

Barrett, S., Dannenberg, A., 2012. Climate negotiaitons under scientific uncertainty. Proceedings of the National Academy of Sciences 109 (43), 17372–17376.

Barrie, L., Bottenheim, J., Schnell, R., Crutzen, P., Rasmussen, R., 1988. Ozone destruction and photochemical reactions at polar sunrise in the lower Arctic atmosphere. Nature 334, 138–141.

Barrie, L., Gregor, D., Hargrave, B., Lake, R., Muir, D., Shearer, R., Tracey, B., Bidleman, T., 1992. Arctic contaminants: sources, occurrence and pathways. Science of the Total Environment 122 (1), 1–4.

Barrie, L., Hoff, R., Daggupaty, S., 1981. The influence of mid-latitudinal pollution sources on haze in the canadian Arctic. Atmospheric Environment (1967) 15 (8), 1407–1419.

Barrie, L. A., 1986. Arctic air pollution: an overview of current knowledge. Atmospheric Environment (1967) 20 (4), 643–663.

Barry, R. G., Hare, F. K., 1974. Arctic climate. Arctic and Alpine Environments, 17–54.

Beach, D., 2012. Taking mechanisms seriously. European Political Science 12 (1), 13–15.

Beard, J., 2006. DDT and human health. Science of the Total Environment 355 (1), 78–89.

Beck, U., 2009. World at risk. Polity Press: Cambridge.

Benedick, R. E., 1998. Ozone Diplomacy. Harvard University Press: Cambridge.

Berkner, L. V., Marshall, L., 1965. On the origin and rise of oxygen concentration in the earth's atmosphere. Journal of Atmospheric Sciences 22 (3), 225–261.

Berry, C., 1967. Organic pesticides in the environment. American Journal of Public Health and the Nations Health 57 (12), 2219–2219.

Bertazzi, P. A., Bernucci, I., Brambilla, G., Consonni, D., Pesatori, A. C., 1998. The seveso studies on early and long-term effects of dioxin exposure: a review. Environmental Health Perspectives 106 (Suppl 2), 625.

Bertazzi, P. A., Riboldi, L., Pesatori, A., Radice, L., Zocchetti, C., 1987. Cancer mortality of capacitor manufacturing workers. American Journal of Industrial Medicine 11 (2), 165–176.

Bernek, M., 2005. Pops pesticides in the czech republic. The International POPs Elimination Project.
URL http://ipen.org/sites/default/files/documents/2ceh_pops_Pesticides_in_czech_republic-en.pdf

Bhattacharya, R., Pal, S., Bhoumick, A., Karmakar, S., 2012. A survey on ultraviolet radiation and ozone research. International Journal of Engineering Science and Technology 4 (9), 4209–4216.

Blaikie, P., 1995. Changing environments or changing views? a political ecology for developing countries. Geography, 203–214.

Blair, A., Zahm, S. H., Pearce, N. E., Heineman, E. F., Fraumeni Jr, J. F., 1992. Clues to cancer etiology from studies of farmers. Scandinavian Journal of Work, Environment & Health 18, 209–215.

Blanchet, J.-P., 1989. Toward estimation of climatic effects due to Arctic aerosols. Atmospheric Environment (1967) 23 (11), 2609–2625.

Bloom, E. T., 1999. Establishment of the Arctic council. Amercan Journal of International Law 93, 712–988.

Blum, A., 1977. Flame-retardant additives as possible cancer. Science 195 (17).

Blyth, M. M., 1997. Ideas and foreign policy: Beliefs, institutions and political change. Comparative Politics 29 (2), 229–250.

Boehmer-Christiansen, 1997. Uncertainty in the service of science. between science politics and the politics of sciences. In: Ferman, G. (Ed.), International Politics of Climate Change. Scandinavian University Press: Oslo, pp. 8–32.

Bogdal, C., Schmid, P., Kohler, M., Müller, C. E., Iozza, S., Bucheli, T. D., Scheringer, M., Hungerbühler, K., 2008. Sediment record and atmospheric deposition of brominated flame retardants and organochlorine compounds in lake thun, switzerland: lessons from the past and evaluation of the present. Environmental Science & Technology 42 (18), 6817–6822.

Bolin, B., 1977. Changes of land biota and their importance for the carbon cycle. Science (New York, N.Y.) 196 (4290), 613–615.

Bonan, G. B., 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science 320 (5882), 1444–1449.

Bonan, G. B., Thompson, S. L., Pollard, D., 1992. Effects of boreal forest vegetation on global climate. Nature 359 (6397), 716–718.

Bond, T. C., Bhardwaj, E., Dong, R., Jogani, R., Jung, S., Roden, C., Streets, D. G., Trautmann, N. M., 2007. Historical emissions of black and organic carbon aerosol from energy-related combustion, 1850–2000. Global Biogeochemical Cycles 21 (2).

Brady, H. E. (Ed.), 2010. Rethinking Social Inquiry. Rowman & Littlefield: Lanham.

Brady, N., 1967. Agriculture and the quality of our environment. In: Brady, N. (Ed.), Agriculture and the quality of our environment. American Association for the Advancement of Science, pp. 460–473.

Breitmeier, H., Young, O. R., Zürn, M., 2006. Analyzing International Environmental Regimes. MIT Press: Cambridge.

Breivik, K., Alcock, R., Li, Y.-F., Bailey, R. E., Fiedler, H., Pacyna, J. M., 2004. Primary sources of selected pops: regional and global scale emission inventories. Environmental Pollution 128 (1), 3–16.

Bridgman, H., Schnell, R., Kahl, J., Herbert, G., Joranger, E., 1989. A major haze event near point Barrow, Alaska: Analysis of probable source regions and transport pathways. Atmospheric Environment (1967) 23 (11), 2537–2549.

Brouwer, A., Longnecker, M. P., Birnbaum, L. S., Cogliano, J., Kostyniak, P., Moore, J., Schantz, S., Winneke, G., 1999. Characterization of potential endocrine-related health effects at low-dose levels of exposure to PCBs. Environmental Health Perspectives 107 (Suppl 4), 639.

Brown, D. P., 1987. Mortality of workers exposed to polychlorinated biphenylsan update. Archives of Environmental Health: An International Journal 42 (6), 333–339.

Brucker-Davis, F., Wagner-Mahler, K., Delattre, I., Ducot, B., Ferrari, P., Bongain, A., Kurzenne, J.-Y., Mas, J.-C., Fnichel, P., 2008. Cryptorchidism at birth in Nice area (france) is associated with higher prenatal exposure to PCBs and DDE, as assessed by colostrum concentrations. Human Reproduction 23 (8), 1708–1718.

Burkow, I. C., Kallenborn, R., 2000. Sources and transport of persistent pollutants to the Arctic. Toxicology letters 112, 87–92.

Bush, B., Bennett, A. H., Snow, J. T., 1986. Polychlorobiphenyl congeners, p, p-DDE, and sperm function in humans. Archives of Environmental Contamination and Toxicology 15 (4), 333–341.

Cameron, G., Burgess, F., 1945. The toxicity of DDT. British Medical Journal 1 (4407), 865–871.

Cammarano, G., Crosignani, P., Berrino, F., Berra, G., 1984. Cancer mortality among workers in a thermoelectric power plant. Scandinavian Journal of Work, Environment & Health, 259–261.

Canters, K., De Snoo, G., 1993. Chemical threat to birds and mammals in the netherlands. In: de Voogt, P. (Ed.), Reviews of Environmental Contamination and Toxicology. Springer: Berlin, pp. 1–29.

Cantor, K. P., Blair, A., Everett, G., Gibson, R., Burmeister, L. F., Brown, L. M., Schuman, L., Dick, F. R., 1992. Pesticides and other agricultural risk factors for non-hodgkin's lymphoma among men in iowa and minnesota. Cancer Research 52 (9), 2447–2455.

Carlson, T. N., 1981. Speculations on the movement of polluted air to the Arctic. Atmospheric Environment (1967) 15 (8), 1473–1477.

Carson, R., 1962. Silent Spring. Houghton Mifflin Harcourt: Boston.

Cess, R. D., 1983. Arctic aerosols: Model estimates of interactive influences upon the surface-atmosphere clearsky radiation budget. Atmospheric Environment (1967) 17 (12), 2555–2564.

Chalmers, A. F., 1990. Science and its Fabrication. University of Minnesota Press: Minneapolis.

Chapman, S., 1930. A theory of atmospheric ozone. Memoranda of Royal MeteoroLogical Society 2, 103–125.

Checkel, J. T., 2008. Process tracing. In: Klotz, A., Prakash, D. (Eds.), Qualitative Methods in International Relations - a Pluralist Guide. Palgrave Macmillan: Basingstoke, pp. 114–129.

Chen, C., 2006. Citespace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. Journal of the American Society for Information Science and Technology 57 (3), 359–377.

Cheng, M. D., Hopke, P. K., Barrie, L., Rippe, A., Olson, M., Landsberger, S., 1993. Qualitative determination of source regions of aerosol in canadian high Arctic. Environmental Science & Technology 27 (10), 2063–2071.

Chwieroth, J. M., 2007. Testing and measuring the role of ideas: The case of neoliberalism in the international monetary fund. International Studies Quarterly 51 (1), 5–30.

Clark, W. C., 2001. Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion, and Acid Rain. Vol. 1. MIT Press: Cambridge.

Clarke, A. D., Noone, K. J., 1985. Soot in the Arctic snowpack: A cause for perturbations in radiative transfer. Atmospheric Environment (1967) 19 (12), 2045–2053.

Climatic Impact Committee, 1975. Environmental Impact of Stratospheric Flight: Biological and Climate Effects of Aircraft Emissions in the Stratosphere. National Academy of Sciences.

Collier, D., 2011. Understanding process tracing. Political Science & Politics 44 (04), 823–830.

Covaci, A., Hura, C., Schepens, P., 2001. Selected persistent organochlorine pollutants in romania. Science of the Total Environment 280 (1), 143–152.

Crutzen, P. J., 1970. The influence of nitrogen oxides on the atmospheric ozone content. Quarterly Journal of the Royal Meteorological Society 96 (408), 320–325.

Crutzen, P. J., 2006. Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma? Climatic Change 77 (3), 211–220.

Dalvie, M. A., Myers, J. E., Thompson, M. L., Robins, T. G., Dyer, S., Riebow, J., Molekwa, J., Jeebhay, M., Millar, R., Kruger, P., 2004. The long-term effects of DDT exposure on semen, fertility, and sexual function of malaria vector-control workers in limpopo province, south africa. Environmental Research 96 (1), 1–8.

Dar, E., Kanarek, M. S., Anderson, H. A., Sonzogni, W. C., 1992. Fish consumption and reproductive outcomes in green bay, wisconsin. Environmental Research 59 (1), 189–201.

Davidson, C. I., Honrath, R. E., Kadane, J. B., Tsay, R. S., Mayewski, P. A., Lyons, W. B., Heidam, N. Z., 1987. The scavenging of atmospheric sulfate by Arctic snow. Atmospheric Environment (1967) 21 (4), 871–882.

Davidson, C. I., Jaffrezo, J.-L., Small, M. J., Summers, P. W., Olson, M. P., Borys, R. D., 1993. Trajectory analysis of source regions influencing the south greenland ice sheet during the dye 3 gas and aerosol sampling program. Atmospheric Environment. Part A. General Topics 27 (17), 2739–2749.

Dawes, R. M., 1975. Formal models of dilemmas in social decision making. In: Kaplan, M.F. Schwartz, S. (Ed.), Human Judgement and Decission Process: Formal and Mathematical Approaches. Academic Press: New York, pp. 1–21.

De Mesquita, B. B., Morrow, J. D., Zorick, E. R., 1997. Capabilities, perception, and escalation. American Political Science Review, 15–27.

Diffey, B., 2004. Climate change, ozone depletion and the impact on ultraviolet exposure of human skin. Physics in Medicine and Biology 49 (1), R1.

Dillon, M., 2013. Deconstructing international politics. Interventions. Routledge: London, London [u.a.].

Dimitrov, R. S., 2003. Knowledge, power, and interests in environmental regime formation. International Studies Quarterly 47 (1), 123–150.

Dimitrov, R. S., 2005. Hostage to norms: States, institutions and global forest politics. Global Environmental Politics 5 (4), 1–24.

Dimitrov, R. S., 2006. Science and International Environmental Policy: Regimes and Non–Regimes in Global Governance. Rowman & Littlefield: Oxford.

Dimitrov, R. S., Sprinz, D., DiGiusto, G. M., Kelle, A., 2007. International non-regimes: A research agenda. International Studies Review 9, 230–258.

Dimitrova, A., Stoyanova, Y., Tachev, A., 2011. Distribution and risk assessment of polychlorinated biphenyls (PCBs) in urban soils of sofia city, bulgaria. Recent Advances in Chemical Engineering, Biochemistry and Computational Chemistry.

Ditraglia, D., Brown, D. P., Namekata, T., Iverson, N., 1981. Mortality study of workers employed at organochlorine pesticide manufacturing plants. Scandinavian Journal of Work, Environment & Health, 140–146.

Djupström, M., Pacyna, J., Maenhaut, W., Winchester, J., Li, S.-M., Shaw, G., 1993. Contamination of Arctic air at three sites during a haze event in late winter 1986. Atmospheric Environment. Part A. General Topics 27 (17), 2999–3010.

Doane, C. C., 1962. Effects of certain insecticides on earthworms. Journal of Economic Entomology 55, 416–421.

Dommarco, R., Di Muccio, A., Camoni, I., Gigli, B., 1987. Organochlorine pesticide and polychlorinated biphenyl residues in human milk from rome (Italy) and surroundings. Bulletin of Environmental Contamination and Toxicology 39 (6), 919–925.

Downs, G. W., Rocke, D. M., 1990. Tacit Bargaining, Arms Races, and Arms Control. University of Michigan Press: Ann Arbor.

Dryzek, J. S., Downes, D., Hunold, C., Schlosberg, D., Hernes, H.-K., 2003. Green States and Social Movements: Environmentalism in the United States, United Kingdom, Germany, and Norway: Environmentalism in the United States, United Kingdom, Germany, and Norway. Oxford University Press: Oxford.

Eckley-Selin, N., 2006. From regional to global information: Assessment of persistent organic pollutants. In: Mitchell, R., Clark, W., Cash, D., , Dickson, N. (Eds.), Global environmental assessments: information and influence. MIT Press: Cambridge, pp. 1–50.

Edwards, C., 1965. Effects of pesticide residues on soil inverterebles and plants. Ecology and the Industrial Society, 239–249.

Edwards, C., 1966. Insecticide residues in soils. Residue Revenue 13 (8), 132–153.

Edwards, C. A., Adams, R., 1970. Persistent pesticides in the environment. Critical Reviews in Environmental Science and Technology 1 (1-4), 7–67.

Egan, H., Goulding, R., Roburn, J., Tatton, J., 1965. Organo-chlorine pesticide residues in human fat and human milk. British Medical Journal 2 (5453), 66.

Enkvist, P., Nauclér, T., Rosander, J., 2007. A cost curve for greenhouse gas reduction. McKinsey Quarterly 1, 34.

Enting, I., Trudinger, C., Francey, R., 1995. A synthesis inversion of the concentration and $\delta 13$ c of atmospheric co2. Tellus B 47 (1-2), 35–52.

Eriksson, M., Hardell, L., Berg, N., Möller, T., Axelson, O., 1981. Soft-tissue sarcomas and exposure to chemical substances: a case-referent study. British Journal of Industrial Medicine 38 (1), 27–33.

Fabian, P., 1978. Ozone increase from concorde operations? Nature 272, 306–307.

Fan, S., Gloor, M., Mahlman, J., Pacala, S., Sarmiento, J., Takahashi, T., Tans, P., 1998. A large terrestrial carbon sink in north America implied by atmospheric and oceanic carbon dioxide data and models. Science 282 (5388), 442–446.

FAO, 1948. World forest resources 1948. Tech. rep., United Nations Food and Agricultural Organization, Rome.

FAO, 1958. World forest resources 1958. Tech. rep., United Nations Food and Agricultural Organization, Rome.

FAO, 1990. Global forest resources assessment 1990. Tech. rep., United Nations Food and Agricultural Organization, Rome.

FAO, 1995. World forest resources 1995. Tech. rep., United Nations Food and Agricultural Organization, Rome.

FAO, 2000. Global forest resources assessment 2000. Tech. rep., United Nations Food and Agricultural Organization, Rome.

FAO, 2005. Global forest resources assessment 2005. Tech. rep., United Nations Food and Agricultural Organization, Rome.

FAO, 2010. Global forest resources assessment 2010. Tech. rep., United Nations Food and Agricultural Organization, Rome.

Farrell, A. E., 2006. Assessments of Regional and Global Environmental Risks: Designing Processes for the Effective Use of Science in Decisionmaking. RFF Press: Washington.

Fearon, J. D., 1997. Signaling foreign policy interests: Tying hands versus sinking costs. Journal of Conflict Resolution 41 (1), 68–90.

Fiedler, H., 1997. 12. polychlorinated biphenyls (PCBs): Uses and environmental releases.
URL http://www.chem.unep.ch/pops/POPs_Inc/proceedings/bangkok/FIEDLER1.html

Finus, M., 2002. Game theory and international environmental cooperation: any practical application? Controlling Global Warming: Perspectives from Economics, Game Theory and Public Choice, 9–104.

Flanner, M. G., Zender, C. S., Hess, P., Mahowald, N. M., Painter, T. H., Ramanathan, V., Rasch, P., 2009. Springtime warming and reduced snow cover from carbonaceous particles. Atmospheric Chemistry and Physics 9 (7), 2481–2497.

Foucault, M., 2008. Power, Knowledge. Longman, Pearson Education: New York.

Frank, U., Greiner, P., Helmich, S., Nenno, W., Preuss, G., Schulte, C., 2007. 25 jahre chemikaliengesetz. Umweltwissenschaften und Schadstoff-Forschung 19 (1), 1–3.

Frankel, J. A., 1988. Obstacles to international macroeconomic policy coordination. Journal of Public Policy, 353–374.

Frankel, J. A., Rockett, K., 1988. International macroeconomic policy coordination when policy-makers disagree on the model.

Fry, D. M., Toone, C. K., et al., 1981. DDT-induced feminization of gull embryos. Science 213 (4510), 922.

G8 Information Centre, July 1990. Houston economic declaration. URL http://www.g8.utoronto.ca/summit/1990houston/declaration.html

Gajski, G., Gerić, M., Ravlić, S., Capuder, Ž., Garaj-Vrhovac, V., 2012. Presence of dichlorodiphenyltrichloroethane (DDT) in croatia and evaluation of its genotoxicity. In: Perveen, F. (Ed.), Croatia and Evaluation of Its Genotoxicity, Insecticides - Pest Engineering. InTech, Ch. 6, pp. 1–35.

Garabrant, D. H., Held, J., Langholz, B., Peters, J. M., Mack, T. M., 1992. DDT and related compounds and risk of pancreatic cancer. Journal of the National Cancer Institute 84 (10), 764–771.

Garfield, E., 1979. Is citation analysis a legitimate evaluation tool? Scientometrics 1 (4), 359–375.

Geddes, B., 2003. Paradigms and Sand Castles: Theory Building and Research Design in Comparative Politics. University of Michigan Press: Ann Arbor.

George, A. L., Bennett, A., 2005. Case Studies and Theory Development in the Social Sciences. MIT Press: Cambridge.

Ghosh, A., 1988. International policy coordination in a world with model uncertainty. Staff Papers - International Monetary Fund 35 (2), 230–258.

Gibbard, S., Caldeira, K., Bala, G., Phillips, T. J., Wickett, M., 2005. Climate effects of global land cover change. Geophysical Research Letters 32 (23), 1–4.

Gladen, B. C., Rogan, W. J., Hardy, P., Thullen, J., Tingelstad, J., Tully, M., 1988. Development after exposure to polychlorinated biphenyls and dichlorodiphenyl dichloroethene transplacentally and through human milk. The Journal of Pediatrics 113 (6), 991–995.

Goertz, G., 2006. Social Science Concepts. Princeton University Press: Princeton.

Goldgeier, James M. Tetlock, P. E., 2001. Psychology and international relations theory. Annual Review of Political Science 4 (1), 67–92.

Goldstein, J., Keohane, R. O., 1993. Ideas and Foreign Policy: Beliefs, Institutions, and Political Change. Cornell University Press: Ithaca.

Gotz, F. P., Meetham, A. R., Dobson, G. M. B., 1934. The vertical distribution of ozone in the atmosphere. Proceedings of the Royal Society of London. Series A 145 (855), 416 446.

Goutner, V., Charalambidou, I., Albanis, T., 1997. Organochlorine insecticide residues in eggs of the little tern (sterna albifrons) in the axios delta, greece. Bulletin of Environmental Contamination and Toxicology 58 (1), 61–66.

Grace, J., Lloyd, J., McIntyre, J., Miranda, A. C., Meir, P., Miranda, H. S., Nobre, C., Moncrieff, J., Massheder, J., Malhi, Y., et al., 1995. Carbon dioxide uptake by an undisturbed tropical rain forest in southwest amazonia, 1992 to 1993. Science, 778–778.

Gramsci, A., 1980. Favole di libertà. Vallecchi: Firenze.

Grayson, A. J. Maynard, W. B., 1997. The World's Forests – Rio +5: Intenational Initiatives toWards Sustainable Management. Commonwealth Foresty Association: Oxford.

Greenaway, K. R., 1950. Experiences With Arctic Flying Weather. Royal MeteoroLogical Society, Canadian Branch.

Gregor, D., Gummer, W. D., 1989. Evidence of atmospheric transport and deposition of organochlorine pesticides and polychlorinated biphenyls in canadian Arctic snow. Environmental Science & Technology 23 (5), 561–565.

Grieco, J. M., 1988. Anarchy and the limits of cooperation: a realist critique of the newest liberal institutionalism. International Organization 42 (03), 485–507.

Groot, A. D., Spiekerman, J. A., 1969. Methodology: Foundations of inference and research in the behavioral sciences. Mouton: The Hague.

Gustavsson, P., Hogstedt, C., Rappe, C., 1986. Short-term mortality and cancer incidence in capacitor manufacturing workers exposed to polychlorinated biphenyls (PCBs). American Journal of Industrial Medicine 10 (4), 341–344.

Haas, E. B., 1975. Is there a hole in the whole? knowledge, technology, interdependence, and the construction of international regimes. International Organization 29 (3), 827–876.

Haas, E. B., 1980. Why collaborate? Issue-linkage and international regimes. World Politics 32 (03), 357–405.

Haas, P. M., 1992a. Banning chlorofluorocarbons: Epistemic community efforts to protect stratospheric ozone. International Organization 46 (1), 187–224.

Haas, P. M., 1992b. Epistemic communities and international policy coordination: Introduction. International Organization 46 (1), 1–35.

Haggard, Stephan Simmons, B. A., 1987. Theories of international regimes. International Organization 41 (3), 491–517.

Hall, A. F., 1950. Relationships of sunlight, complexion and heredity to skin carcinogenesis. Archives of Dermatology and Syphilology 61 (4), 589–610.

Hammond, A. L., 1972. Chemical pollution: Polychlorinated biphenyls. Science 175 (4018), 155–156.

Hampson, J., 1964. Photochemical Behaviour of the Ozone Layer. Canadian Armament Research and Development Establishment.

Hanley, N., Barbier, E. B., Barbier, E., 2009. Pricing Nature: Cost-Cenefit Analysis and Environmental Policy. Edward Elgar Publishing: Northampton.

Hansen, A., Novakov, T., 1989. Aerosol black carbon measurements in the Arctic haze during AGASP-II. Journal of Atmospheric Chemistry 9 (1-3), 347–361.

Hansen, J., Nazarenko, L., 2004. Soot climate forcing via snow and ice albedos. Proceedings of the National Academy of Sciences of the United States of America 101 (2), 423–428.

Hardin, G., 1968. The tragedy of the commons. Science 162 (3859), 1243–1248.

Harrison, H., 1970. Stratospheric ozone with added water vapor: influence of high-altitude aircraft. Science 170 (3959), 734–736.

Hartmann, P. C., Quinn, J. G., Cairns, R. W., King, J. W., 2005. Depositional history of organic contaminants in narragansett bay, rhode island, usa. Marine Pollution Bulletin 50 (4), 388–395.

Hasenclever, A., Mayer, P., Rittberger, V., 1996. Interests, power, knowledge: The study of international regimes. International Studies Quarterly 40, 177–228.

Hasenclever, A., Mayer, P., Rittberger, V., 1997. Theories of International Regimes. Cambridge University Press: Cambridge.

Hasenclever, A., Mayer, P., Rittberger, V., 2000. Integrating theories of international regimes. Review of International Studies 26 (1), 3–33.

Hayes, W., Dale, W., Lebreton, R., 1963. Storage of insecticides in french people. Nature 199, 1189–1191.

Hayes, W., Durham, W., Cueto Jr, C., 1956. The effect of known repeated oral doses of chlorophenothane (DDT) in man. Journal of the American Medical Association 162 (9), 890–897.

Hegde, D., 2009. Political influence behind the veil of peer review: an analysis of public biomedical research funding in the united states. Journal of Law and Economics 52 (4), 665–690.

Heidam, N. Z., 1984. The components of the Arctic aerosol. Atmospheric Environment (1967) 18 (2), 329–343.

Heintzenberg, J., Hansson, H.-C., Lannefors, H., 1981. The chemical composition of arctic haze at ny-ålesund, spitsbergen. Tellus 33 (2), 162–171.

Helleiner, E., 2008. The mystery of the missing sovereign debt restructuring mechanism. Contributions to Political Economy 27 (1), 91–113.

Helm, C., 1998. International cooperation behind the veil of uncertainty - the case of transboundary acidification. Environmental & Resource Economics 12, 185–201.

Helm, Carsten Sprinz, D., 2000. Measuring the effectiveness of international environmental regimes. Journal of Conflict Resolution 44 (5), 630–652.

Hernandez, L. M., Rico, M. C., Gonzalez, M. J., Hernan, M. A., Fernandez, M. A., 1986. Presence and time trends of organochlorine pollutants and heavy metals in eggs of predatory birds of spain. Journal of Field Ornithology, 270–282.

Hickey, J. J., Anderson, D. W., 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162, 271–273.

Hinck, J. E., Norstrom, R. J., Orazio, C. E., Schmitt, C. J., Tillitt, D. E., 2009. Persistence of organochlorine chemical residues in fish from the tombigbee river (alabama, usa): Continuing risk to wildlife from a former DDT manufacturing facility. Environmental Pollution 157 (2), 582–591.

Holtham, G., Hughes Hallett, A., 1987. International policy cooperation and model uncertainty. Tech. rep., CEPR Discussion Papers.

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K., Johnson, C., 2001. Climate Change 2001: The Scientific Basis. Vol. 881. Cambridge University Press: Cambridge.

Hovi, J., Sprinz, D. F., Underdal, A., 2003. The oslo-potsdam solution to measuring regime effectiveness: Critique, response, and the road ahead. Global Environmental Politics 3 (3), 74–96.

Humphreys, D., 2006. Logjam: Deforestation and the crisis of global governance. Cambridge University Press: Cambridge.

Hunt, B. G., 1966. Photochemistry of ozone in a moist atmosphere. Journal of Geophysical Research 71 (5), 1385–1398.

IARC, 1987. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Vol. 43. World Health Organization.

IARC, 2013. Agents classified by the iarc monographs.
URL http://monographs.iarc.fr/ENG/Classification/ClassificationsAlphaOrder.pdf

Ichihashi, M., Ueda, M., Budiyanto, A., Bito, T., Oka, M., Fukunaga, M., Tsuru, K., Horikawa, T., 2003. Uv-induced skin damage. Toxicology 189 (1), 21–39.

Iida, K., 1993. Analytic uncertainty and international cooperation: Theory and application to international economic policy coordination. International Studies Quarterly, 431–457.

IISD, 1995. Earth negotiation bulletin. Special Report on International Forests Policy Activities 13, 1–6.

IPCC, 1990. Climate Change: The IPCC Scientific Assessment. Cambridge University Press: Cambridge.

IPCC, 1996. Climate Change 1995: The Science of Climate Change, 1st Edition. Cambridge University Press: Cambridge.

IPCC, 2007a. Climate Change 2007: Impacts, Adaptation and Vulnerability; Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Changes, 1st Edition. Cambridge Univiversity Press: Cambridge.

IPCC, 2007b. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Vol. 446. Cambridge University Press: Cambridge.

IPCC, 2007c. Climate Change 2007-The Physical Science Basis: Working Croup I Contribution to the Fourth Assessment Report of the IPCC. Vol. 4. Cambridge University Press: Cambridge.

Iversen, T., Joranger, E., 1985. Arctic air pollution and large scale atmospheric flows. Atmospheric Environment (1967) 19 (12), 2099–2108.

Jachtenfuchs, M., 1995. Ideen und internationale beziehungen. Zeitschrift für Internationale Beziehungen, 417–442.

Jacobson, M. Z., 2001. Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. Nature 409 (6821), 695–697.

Jacobson, M. Z., 2010. Short-term effects of controlling fossil-fuel soot, biofuel soot and gases, and methane on climate, Arctic ice, and air pollution health. Journal of Geophysical Research 115 (D14).

Janusch, H., 2012. Das scheitern von internationalen verhandlungen. forthcoming.

Jensen, S., 1966. Report of a new chemical hazard. New Scientist 32 (525), 612.

Jervis, R., 1976. Perception and Misperception in International Politics. Vol. 49. Princeton University Press: Princeton.

Johnson, D., 1968. Pesticides and fishesa review of selected literature. Transactions of the American Fisheries Society 97 (4), 398–424.

Johnson, F. S., 1972. Ozone and SSTs. Biological Conservation 4 (3), 220–222.

Johnston, H., 1971. Reduction of stratospheric ozone by nitrogen oxide catalysts from supersonic transport exhaust. Science 173 (3996), 517–522.

Jones, K., De Voogt, P., 1999. Persistent organic pollutants (pops): State of the science. Environmental Pollution 100 (1), 209–221.

Kaly, U. L., Commission, S. P. A. G., et al., 1999. Environmental Vulnerability Index (EVI) to Summarise National Environmental Vulnerability Profiles. Vol. 275. South Pacific Applied Geoscience Commission Suva: Fiji.

Keeling, C. D., 1970. Is carbon dioxide from fossil fuel changing man's environment? Proceedings of the American Philosophical Society, 10–17.

Keith, J., 1966. Insecticide contaminations in wetland habitats and their effects on fish-eating birds. Journal of Applied Ecology 71 (3), 71–85.

Kennedy, P., 2010. The Rise and Fall of the Great Powers. Random House: New York.

Keohane, R., 1989. Reciprocity in international relations. International Organization 40 (1).

Keohane, R. O., 1982. The demand for international regimes. International Organization 36 (2), 325–355.

Keohane, R. O., 1984. After Hegemony: Cooperation and Discord in the World Political Economy. Princeton University Press: Princeton.

Keohane, R. O., Nye, J. S., 1977. Power and Interdependence: World Politics in Transition, 1st Edition. Little, Brown: London, Boston [u.a.].

Kerr, R. A., 1979. Global pollution: is the arctic haze actually industrial smog? Science 205 (4403), 290–293.

Kimbrough, R. D. (Ed.), 1989. Halogenated Biphenyls, Terphenyls, Naphthalenes, Dibenzodioxins and Related Products, 2nd Edition. No. 4 in Topics in Environmental Health. Elsevier: Amsterdam.

Kimbrough, R. D., Squire, R. A., Linder, R. E., Strandberg, J. D., Montali, R. J., Burse, V. W., 1975. Induction of liver tumors in sherman strain female rats by polychlorinated biphenyl aroclor 1260. Journal of the National Cancer Institute 55 (6), 1453–1459.

Kindleberger, C. P., 1981. Dominance and leadership in the international economy: exploitation, public goods, and free rides. International Studies Quarterly, 242–254.

Kindleberger, C. P., 1986. The World in Depression, 1929-1939. Vol. 4. University of California Press: Oakland.

Kindleberger, C. P., 1988. The International Economic Order: Essays on Financial Crisis and International Public Goods. MIT Press Cambridge: Cambridge.

King, G., Keohane, R. O., Verba, S., 1994. Designing Social Inquiry: Scientific Inference in Qualitative Research. Princeton University Press: Princeton.

Kittel, B., Kuehn, D., 2012. Introduction: Reassessing the methodology of process tracing. European Political Science 12 (1), 1–9.

Knight, F. H., 1965. Risk, Uncertainty and Profit, 1st Edition. Harper Torchbooks. Harper & Row: New York.

Kolstad, C. D., 2000. Environmental Economics. Vol. 15. Oxford University Press: Oxford.

Kolstad, C. D., 2005. Piercing the veil of uncertainty in transboundary pollution agreements. Environmental and Resource Economics 31 (1), 21–34.

Kolstad, C. D., 2007. Systematic uncertainty in self-enforcing international environmental agreements. Journal of Environmental Economics and Management 53 (1), 68–79.

Kolstad, C. D., Ulph, A., 2011. Uncertainty, learning and heterogeneity in international environmental agreements. Environmental & Resource Economics 50 (3), 389–403.

Konstantinou, I., Goutner, V., Albanis, T., 2000. The incidence of polychlorinated biphenyl and organochlorine pesticide residues in the eggs of the cormorant (phalacrocorax carbo sinensis): An evaluation of the situation in four greek wetlands of international importances. Science of the Total Environment 257 (1), 61–79.

Koremenos, B., 2005. Contracting around international uncertainty. American Political Science Review 99 (4), 549–565.

Koremenos, B., Lipson, C., Snidal, D., 2001. The rational design of international institutions. International Organization 55 (04), 761–799.

Krasner, S., 1983. International Regimes. Cornell University Press: Ithaca.

Krieger, N., Wolff, M. S., Hiatt, R. A., Rivera, M., Vogelman, J., Orentreich, N., 1994. Breast cancer and serum organochlorines: a prospective study among white, black, and Asian women. Journal of the National Cancer Institute 86 (8), 589–599.

Krueger, J., Selin, H., 2002. Governance for sound chemicals management: The need for a more comprehensive global strategy. Global Governance, 323–342.

Kuznyetsov, V., 2008. Problem of pops management in ukraine: the lack of interdepartmental cooperation and public involvement. In: The Fate of Persistent Organic Pollutants in the Environment. Springer: Berlin, pp. 51–64.

Kveseth, N., Bjerk, J., Fimreite, N., Stenersen, J., 1979. Residues of DDT in a Norwegian fruitgrowing district two and four years after the termination of DDT usage. Archives of Environmental Contamination and Toxicology 8 (2), 201–212.

Kydd, A., 2001. Trust building, trust breaking: The dilemma of nato enlargement. International Organization 55 (4), 801–828.

Kydd, A., Snidal, D., 1997. Progress in game-theoretical analysis of international regimes. In: Rittberger, V. (Ed.), Regime Theory and International Relations. Oxford University Press: Oxford, pp. 8–28.

LaDou, J., 2004. The asbestos cancer epidemic. Environmental Health Perspectives 112 (3), 285.

Lamarque, J.-F., Bond, T. C., Eyring, V., Granier, C., Heil, A., Klimont, Z., Lee, D., Liousse, C., Mieville, A., Owen, B., et al., 2010. Historical (1850–2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: Methodology and application. Atmospheric Chemistry and Physics 10 (15), 7017–7039.

Landman, T., 2008. Issues and Methods in Comparative Politics, 3rd Edition. Routledge: London.

Lange, A., Vogt, C., 2003. Cooperation in international environmental negotiaitons due to a preference for equity. Journal of Public Economics 87 (9), 2049–2067.

Law, R. J., Bersuder, P., Barry, J., Deaville, R., Reid, R. J., Jepson, P. D., 2010. Chlorobiphenyls in the blubber of harbour porpoises from the uk: Levels and trends 1991–2005. Marine Pollution Bulletin 60 (3), 470–473.

Lee, X., Goulden, M. L., Hollinger, D. Y., Barr, A., Black, T. A., Bohrer, G., Bracho, R., Drake, B., Goldstein, A., Gu, L., et al., 2011. Observed increase in local cooling effect of deforestation at higher latitudes. Nature 479 (7373), 384–387.

Leighton, H., 1983. Influence of Arctic haze on the solar radiation budget. Atmospheric Environment (1967) 17 (10), 2065–2068.

Lemarchand, C., Amblard, C., Souchon, Y., Berny, P., 2007. Organochlorine compounds (pesticides and PCBs) in scats of the european otter (lutra lutra) from an actual expanding population in central france. Water, Air, and Soil Pollution 186 (1-4), 55–62.

Leoni, V., Fabiani, L., Marinelli, G., Puccetti, G., Tarsitani, G., De Carolis, A., Vescia, N., Morini, A., Aleandri, V., Pozzi, V., et al., 1989. PCB and other organochlorine compounds in blood of women with or without miscarriage: a hypothesis of correlation. Ecotoxicology and Environmental Safety 17 (1), 1–11.

Levit, J. K., 2005. Bottom-up approach to international lawmaking: The tale of three trade finance instruments. Yale Journal of International Law 30, 125.

Levy, J., 1992. Prospect theory and international relations: Theoretical applications and analytical problems. Political Psychology, 283–310.

Levy, J. S., 2008. Case studies: Types, designs, and logics of inference. Conflict Management and Peace Science 25 (1), 1–18.

Li, S.-M., Barrie, L. A., Sirois, A., 1993. Biogenic sulfur aerosol in the Arctic troposphere: Trends and seasonal variations. Journal of Geophysical Research: Atmospheres (1984–2012) 98 (D11), 20623–20631.

Li, Y., 1999. Global technical hexachlorocyclohexane usage and its contamination consequences in the environment: From 1948 to 1997. Science of the Total Environment 232 (3), 121–158.

Li, Y., Macdonald, R. W., 2005. Sources and pathways of selected organochlorine pesticides to the Arctic and the effect of pathway divergence on HCH trends in biota: a review. Science of the Total Environment 342 (1), 87–106.

Lichtenstein, E., 1957. DDT accumulation in mid-western orchard and crop soils treated since 1945. Journal of Economic Entomology 50 (5), 545–547.

Lidskog, R., Sundqvist, G., 2002. The role of science in environmental regimes: The case of LRTAP. European Journal of International Relations 8 (1), 77–101.

Lieberman, R. C., 2002. Ideas, institutions, and political order: Explaining political change. American Political Science Review 96 (04), 697–712.

Lieberson, S., 1991. Small N's and big conclusions: An examination of the reasoning in comparative studies based on a small number of cases. Social Forces 70 (2), 307–320.

Lieberson, S., 1994. More on the uneasy case for using Mill-type methods in small-n comparative studies. Social Forces 72 (4), 1225–1237.

Lijphart, A., 1975. The comparable-cases strategy in comparative research. Comparative Political Studies 8 (2), 158–177.

Likens, G. E., Bormann, F. H., Johnson, N. M., 1972. Acid rain. Environment: Science and Policy for Sustainable Development 14 (2), 33–40.

Littorin, M., Attewell, R., Horstmann, V., Möller, T., et al., 1993. Mortality and tumour morbidity among swedish market gardeners and orchardists. International Archives of Occupational and Environmental Health 65 (3), 163–169.

Lohmann, R., Breivik, K., Dachs, J., Muir, D., 2007. Global fate of POPs: Current and future research directions. Environmental Pollution 150 (1), 150–165.

Longnecker, M., Rogan, W., Lucier, G., 1997. The human health effects of DDT (dichlorodiphenyltrichloroethane) and PCBs (polychlorinated biphenyls) and an overview of organochlorines in public health 1. Annual Review of Public Health 18 (1), 211–244.

Longnecker, M. P., Klebanoff, M. A., Zhou, H., Brock, J. W., 2001. Association between maternal serum concentration of the DDT metabolite DDE and preterm and small-for-gestational-age babies at birth. The Lancet 358 (9276), 110–114.

Lovelock, J. E., 1974. Atmospheric halocarbons and stratospheric ozone. Nature 252, 292–294.

Lovelock, J. E., Maggs, R., Wade, R., 1973. Halogenated hydrocarbons in and over the atlantic. Nature 241, 194–196.

Ludwicki, J., Góralczyk, K., 1994. Organochlorine pesticides and PCBs in human adipose tissues in poland. Bulletin of Environmental Contamination and Toxicology 52 (3), 400–403.

Macdonald, R., Barrie, L., Bidleman, T., Diamond, M., Gregor, D., Semkin, R., Strachan, W., Li, Y., Wania, F., Alaee, M., et al., 2000. Contaminants in the canadian Arctic: 5 years of progress in understanding sources, occurrence and pathways. Science of the Total Environment 254 (2), 93–234.

Mackay, D., Wania, F., 1995. Transport of contaminants to the Arctic: partitioning, processes and models. Science of the Total Environment 160, 25–38.

MacPhee, A. W., Chisholm, D., C.R.MacEachern, 1960. The persistence of certain pesticides in the soil and their effect on crop yields. Canadian Journal of Soil Science 40 (1), 59–62.

Marthinsen, I., Staveland, G., Skaare, J., Ugland, K., Haugen, A., 1991. Levels of environmental pollutants in male and female flounder (platichthys flesus l.) and cod (gadus morhua l.) caught during the year 1988 near or in the waterway of glomma, the largest river of Norway. i. polychlorinated biphenyls. Archives of Environmental Contamination and Toxicology 20 (3), 353–360.

Martin, L. L., Simmons, B. A., 1998. Theories and empirical studies of international institutions. International Organization 52, 729–749.

Mayring, P., 2010. Qualitative Inhaltsanalyse, 11th Edition. Pädagogik. Beltz: Weinheim.

McCarty, N., Meirowitz, A., 2007. Political game theory, 1st Edition. Analytical methods for social research. Cambridge University Press: Cambridge.

McCulloch, A., Midgley, P., Fisher, D., 1994. Distribution of emissions of chlorofluorocarbons (cfcs) 11, 12, 113, 114 and 115 among reporting and non-reporting countries in 1986. Atmospheric Environment 28 (16), 2567–2582.

McDermott, R., 2004. Political Psychology in International Relations. University of Michigan Press: Ann Arbor.

Meigs, J., Albom, J., Kartin, B., 1954. Chloracne from an unusual exposure to arochlor. Journal of the American Medical Association 154 (17), 1417–418.

Mendola, P., Buck, G. M., Vena, J. E., Zielezny, M., Sever, L. E., 1995. Consumption of PCB-contaminated sport fish and risk of spontaneous fetal death. Environmental Health Perspectives 103 (5), 498.

Menon, S., Hansen, J., Nazarenko, L., Luo, Y., 2002. Climate effects of black carbon aerosols in China and India. Science 297 (5590), 2250–2253.

Ministry of Labour and Social Insurance, 2007. Stockholm convention on persistent organic pollutants - national implementation plan. Tech. rep., Insurance.

Mitchell, J., 1957. Visual range in the polar regions with particular reference to the Alaskan Arctic. Journal of Atmospheric and Terrestrial Physics 17, 195–211.

Mitchell, R., 2006. Global environmental assessments: information and influence. In: Mitchell, R., Clark, W., Cash, D., Dickson, N. (Eds.), Global environmental assessments: information and influence. MIT Press, pp. 5–15.

Mitchell, R. B., 2003. International environmental agreements: a survey of their features, formation, and effects. Annual Review of Environment and Resources 28 (1), 429–461.

Mitchell, R. B., Bernauer, T., 2004. Beyond story-telling: designing case study research in international environmental policy. In: Sprinz, D. Wolinsky-Nahmias, Y. (Ed.), Models, Numbers, and Cases: Methods for Studying International Relations. University of Michigan Press: Ann Arbor, pp. 81–106.

Moed, H. F., 2005. Citation analysis of scientific journals and journal impact measures. Current Science-Bangalore 89 (12), 1990–1997.

Moed, H. F., 2010. Measuring contextual citation impact of scientific journals. Journal of Informetrics 4 (3), 265–277.

Molina, M. J., Rowland, F. S., 1974. Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone. Nature 249 (5460), 810–12.

Moore, N., 1967. A synopsis of the pesticide problem. Advances in Ecological Research 4, 75–129.

Moore, N., Tatton, J., 1965. Organochlorine insecticide residues in the eggs of sea birds. Nature 207, 42–43.

Moravcsik, A., 2000. The origins of human rights regimes: Democratic delegation in postwar Europe. International Organization 54 (2), 217–252.

Morrisette, P. M., 1989. Evolution of policy responses to stratospheric ozone depletion, the. Natural Resources Journal 29, 793–820.

Morrow, J. D., 1989. Capabilities, uncertainty, and resolve: A limited information model of crisis bargaining. American Journal of Political Science, 941–972.

Morrow, J. D., 2001. The institutional features of the prisoners of war treaties. International Organization 55 (4), 971–991.

Mosser, J. L., Fisher, N. S., Teng, T.-C., Wurster, C. F., 1972. Polychlorinated biphenyls: toxicity to certain phytoplankters. Science 175 (4018), 191–192.

Na, S., Shin, H. S., 1998. International environmental agreements under uncertainty. Oxford Economic Papers: Oxford 50 (2), 173–185.

Naso, B., Perrone, D., Ferrante, M. C., Bilancione, M., Lucisano, A., 2005. Persistent organic pollutants in edible marine species from the gulf of naples, southern Italy. Science of the Total Environment 343 (1), 83–95.

Nayar, B. R., 1995. Regimes, power, and international aviation. International Organization 49 (1), 139–170.

Nelson, N., 1972. Comments on research needs. Environmental Health Perspectives 1, 181.

Nicholson, W., Seidman, H., Selikoff, I., 1987. Mortality experience of workers exposed to polychlorinated biphenyls during manufacture of electrical capacitors. Report to the industrial disease standards panel. Ontario Ministry of Labor: Ontario.

Noone, K. J., Clarke, A. D., 1988. Soot scavenging measurements in Arctic snowfall. Atmospheric Environment (1967) 22 (12), 2773–2778.

Nordenskiöld, A., 1883. Nordenskiöld on the inland ice of greenland. Science 7 (44), 732–738.

NRC, 1975. Environmental Impact of Stratospheric Flight. National Academy of Sciences: Washington.

NRC, 1976. Halocarbons: effects on Stratospheric Ozone. National Academy of Sciences: Washington.

NRC, 1979a. Stratospheric Ozone Depletion by Halocarbons: Chemistry and Transport. National Academy of Sciences: Washington.

NRC, 1982. Causes and Effects of Changes in Stratospheric Ozone Reduction: An Update. National Academy of Sciences: Washington.

NRC, 1984. Causes and Effects of Changes in Stratospheric Ozone Reduction: An Update 1983. National Academy of Sciences: Washington.

Nriagu, J. O., Coker, R. D., Barrie, L. A., 1991. Origin of sulphur in canadian Arctic haze from isotope measurements. Nature 349, 142–146.

Oatley, T. H., 2001. Multilateralizing trade and payments in postwar Europe. International Organization 55 (4), 949–969.

Ockenden, W. A., Sweetman, A. J., Prest, H. F., Steinnes, E., Jones, K. C., 1998. Towards an understanding of the global atmospheric distribution of persistent organic pollutants: The use of semipermeable membrane devices as time-integrated passive samplers. Environmental Science & Technology 32 (18), 2795–2803.

Oels, A., 2005. Rendering climate change governable: From biopower to advanced liberal government? Journal of Environmental Policy & Planning 7 (3), 185–207.

O'Leary, J., Davies, J. F. M., 1970. Spontanious abortion and human pesticides residues of DDT and DDE. American Journal of Obstetrics and Gynecology 108, 1291–1292.

Olson, M., 1965. The Logic of Collective Action: Public Goods and the Theory of Groups. Vol. 124. Harvard University Press: Cambridge.

Olsson, M., Reutergårdh, L., 1986. DDT and PCB pollution trends in the swedish aquatic environment. Ambio, 103–109.

Opdam, P., Burgers, J., Müskens, G., 1987. Population trend, reproduction, and pesticides in dutch sparrowhawks following the ban on DDT. Ardea 75, 205–212.

Opp, K.-D., 1970. Methodologie der Sozialwissenschaften. No. 339/341 in Rowohlts deutsche Enzyklopädie. Rowohlt: Reinbek.

Ottar, B., 1981. The transfer of airborne pollutants to the Arctic region. Atmospheric Environment (1967) 15 (8), 1439–1445.

Ottar, B., Pacyna, J. M., Berg, T. C., 1986. Aircraft measurements of air pollution in the Norwegian Arctic. Atmospheric Environment (1967) 20 (1), 87–100.

Pacyna, J. M., Breivik, K., Münch, J., Fudala, J., 2003. European atmospheric emissions of selected persistent organic pollutants, 1970-1995. Atmospheric Environment 37, 119–131.

Pacyna, J. M. e. a., 1999. Appendix 1 to executive final summary report "environmental cycling of selected persistent organic pollutants (pops) in the baltic region (popcycling-baltic project). Tech. rep., Environment & Climate Research Programme.

Pahre, R., 2001. Most-favored-nation clauses and clustered negotiations. International Organization 55 (4), 859–890.

Parson, E. A., 2003. Protecting the Ozone Layer: Science and Strategy. Oxford University Press: Oxford.

Parsons, C., 2002. Showing ideas as causes: The origins of the European union. International Organization 56 (1), 47–84.

Parungo, F. P., Nagamoto, C. T., Sheridan, P. J., Schnell, R. C., 1990. Aerosol characteristics of Arctic haze sampled during agasp-ii. Atmospheric Environment. Part A. General Topics 24 (4), 937–949.

Patterson, E., Marshall, B., Rahn, K., 1982. Radiative properties of the Arctic aerosol. Atmospheric Environment (1967) 16 (12), 2967–2977.

Paul, N. D., Gwynn-Jones, D., 2003. Ecological roles of solar uv radiation: towards an integrated approach. Trends in Ecology & Evolution 18 (1), 48–55.

Peakall, D., 1969. Effect of DDT on calcium uptake and vitamin D metabolism in birds. Nature 224, 1219 – 1220.

Petraitis, J., Jarmalaitė, I., Vaičiūnas, V., Uščinas, R., Jankovskienė, G., 2013. A review of research studies into pesticide residues in food in Lithuania. Agriculture 100 (2), 205–212.

Petrik, J., Drobna, B., Pavuk, M., Jursa, S., Wimmerova, S., Chovancova, J., 2006. Serum PCBs and organochlorine pesticides in slovakia: age, gender, and residence as determinants of organochlorine concentrations. Chemosphere 65 (3), 410–418.

Pham, T., Lum, K., Lemieux, C., 1996. Seasonal variation of DDT and its metabolites in the St. Lawrence River (canada) and four of its tributaries. Science of the Total Environment 179, 17–26.

Phillips, O. L., Malhi, Y., Higuchi, N., Laurance, W. F., Laurance, S. G., Nez, P. V., Vsquez, R. M., Ferreira, L. V., Stern, M., Brown, S., Grace, J., 1998. Changes in the carbon balance of tropical forests: Evidence from long-term plots. Science 282 (5388), 439–442.

Pierson, P., 2011. Politics in Time: History, Institutions and Social Analysis. Princeton University Press: Princeton.

Porch, W. M., MacCracken, M. C., 1982. Parametric study of the effects of Arctic soot on solar radiation. Atmospheric Environment (1967) 16 (6), 1365–1371.

Procinoy, Rena Schvartsman, S., 1981. Blood pesticide concentration in mothers and their newborn infants: Relation to prematurity. Acta Paediatrica 70 (6), 925–928.

Pulkrabová, J., Hrádková, P., Hajšlová, J., Poustka, J., Nápravníková, M., Poláček, V., 2009. Brominated flame retardants and other organochlorine pollutants in human adipose tissue samples from the czech republic. Environment International 35 (1), 63–68.

Quinn, P., Shaw, G., Andrews, E., Dutton, E., Ruoho-Airola, T., Gong, S., 2007. Arctic haze: current trends and knowledge gaps. Tellus B 59 (1), 99–114.

Raatz, W. E., Shaw, G. E., 1984. Long-range tropospheric transport of pollution aerosols into the Alaskan Arctic. Journal of Climate and Applied Meteorology 23 (7), 1052–1064.

Rahn, K. A., 1981. Relative importances of north America and Eurasia as sources of Arctic aerosol. Atmospheric Environment (1967) 15 (8), 1447–1455.

Rahn, K. A., 1985. Progress in Arctic air chemistry, 1980–1984. Atmospheric Environment (1967) 19 (12), 1987–1994.

Rahn, K. A., Borys, R. D., Shaw, G. E., 1977. The Asian source of Arctic haze bands. Nature 268, 713–715.

Rahn, K. A., Heidam, N. Z., 1981. Progress in Arctic air chemistry, 1977–1980: A comparison of the first and second symposia. Atmospheric Environment (1967) 15 (8), 1345–1348.

Rahn, K. A., Lowenthal, D. H., 1984. Elemental tracers of distant regional pollution aerosols. Science 223 (4632), 132–139.

Rahn, K. A., McCaffrey, R. J., 1980. On the origin and transport of the winter Arctic aerosols. Annals of the New York Academy of Sciences 338 (1), 486–503.

Ramanathan, V., Carmichael, G., 2008. Global and regional climate changes due to black carbon. Nature Geoscience 1 (4), 221–227.

Ramanathan, V., Crutzen, P., Kiehl, J., Rosenfeld, D., 2001. Aerosols, climate, and the hydrological cycle. Science 294 (5549), 2119–2124.

Ramsay, K. W., 2011. Cheap talk diplomacy, voluntary negotiations, and variable bargaining power1. International Studies Quarterly 55 (4), 1003–1023.

Randerson, J., Liu, H., Flanner, M., Chambers, S., Jin, Y., Hess, P., Pfister, G., Mack, M., Treseder, K., Welp, L., et al., 2006. The impact of boreal forest fire on climate warming. Science 314 (5802), 1130–1132.

Ratcliffe, D. A., 1958. Broken eggs in peregrine eyries. British Birds 51, 23–26.

Ratcliffe, D. A., 1967. Decrease in eggshell weight in certain birds of prey. Nature 215, 208–210.

Rathbun, B. C., 2007. Uncertain about uncertainty: understanding the multiple meanings of a crucial concept in international relations theory. International Studies Quarterly 51 (3), 533–557.

Raustiala, K., Victor, D. G., 2004. The regime complex for plant genetic resources. International Organization 58 (2), 277–309.

Richards, J. E., 2001. Institutions for flying: How states built a market in international aviation services. International Organization 55 (4), 993–1017.

Rinke, A., Dethloff, K., Fortmann, M., 2004. Regional climate effects of Arctic haze. Geophysical Research Letters 31 (16), L16202.

Rittberger, V., Mayer, P., 1993. Regime Theory and International Relations. Clarendon Press: Oxford.

Ritter, L., Solomon, K. R., Forget, J., Stemeroff, M., O'leary, C., 1995. A review of selected persistent organic pollutants. International Programme on Chemical Safety (IPCS). World Health Organization 65, 66.

Ritter L., K.R. Solomon, J. F., 1998. Persitent organic pollutants - an assessment report on: DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, hexachlorobenzene, mirex, toxaphene, polychlorinated biphenyls, dioxins and furans. Tech. Rep. UNEP/POPS/INC.1/INF/10, UNEP.

Robbins, C., Springer, P., Webster, C., 1951. Effects of five-year DDT application on breeding bird population. The Journal of Wildlife Management, 213–216.

Robinson, J., McGill, A., 1966. Organochlorine insecticide residues in complete prepared meals in great britain during 1965. Nature 212, 1037–1039.

Rodan, B. D., Pennington, D. W., Eckley, N., Boethling, R. S., 1999. Screening for persistent organic pollutants: techniques to provide a scientific basis for pops criteria in international negotiaitons. Environmental Science & Technology 33 (20), 3482–3488.

Rogan, W. J., Gladen, B. C., McKinney, J. D., Carreras, N., Hardy, P., Thullen, J., Tingelstad, J., Tully, M., 1986a. Polychlorinated biphenyls (PCBs) and dichlorodiphenyl dichloroethene (DDE) in human milk: Effects of maternal factors and previous lactation. American Journal of Public Health 76 (2), 172–177.

Rogan, W. J., Gladen, B. C., McKinney, J. D., Carreras, N., Hardy, P., Thullen, J., Tinglestad, J., Tully, M., 1986b. Neonatal effects of transplacental exposure to PCBs and DDE. The Journal of Pediatrics 109 (2), 335–341.

Rohlfing, I., 2012. Case Studies and Causal Inference. Research Methods series. Palgrave Macmillan: Basingstoke.

Roots, O., Simm, M., Kiviranta, H., Rantakokko, P., 2008. Persistent organic pollutants (POPs): Food safety control in estonia. In: The Fate of Persistent Organic Pollutants in the Environment. Springer, pp. 173–185.

Rosen, H., Hansen, A., 1985. Estimates of springtime soot and sulfur fluxes entering the Arctic troposphere: Implications to source regions. Atmospheric Environment (1967) 19 (12), 2203–2207.

Rosen, H., Novakov, T., Bodhaine, B., 1981. Soot in the Arctic. Atmospheric Environment (1967) 15 (8), 1371–1374.

Rosendorff, P. B., Milner, H. V., 2001. The optimal design of international trade institutions: Uncertainty and escape. International Organization 55 (4), 829–857.

Ross, P. S., 2006. Fireproof killer whales (orcinus orca): Flame-retardant chemicals and the conservation imperative in the charismatic icon of british columbia, canada. Canadian Journal of Fisheries and Aquatic Sciences 63 (1), 224–234.

Rowland, F. S., Molina, M. J., 1975. Chlorofluoromethanes in the environment. Review of Geophysics 13 (1), 1–35.

Rudd, R., 1964. Pesticides and the living landscape. Soil Science 98 (2), 144–175.

Ruggie, J. G., 1975. International responses to technology: Concepts and trends. International Organization 29, 557–583.

Saxena, M., Siddiqui, M., Bhargava, A., Seth, T., Krishnamurti, C., Kutty, D., 1980. Role of chlorinated hydrocarbon pesticides in abortions and premature labour. Toxicology 17 (3), 323–331.

Schindler, D. W., 1988. Effects of acid rain on freshwater ecosystems. Science 239 (4836), 149–157.

Schmidt, O., 2001. Insecticide contamination at the national museum of Denmark: a case study. Collection Forum 16 (1-2), 92–95.

Selin, H., 2000. Towards International Chemical Safety: Taking Action on Persistent Organic Pollutants. Linköping University Electronic Press: Linköping.

Selin, H., Eckley, N., 2003. Science, politics, and persistent organic pollutants: The role of scientific assessments in international environmental co-operation. International Environmental Agreements: Politics, Law and Economics 3 (1), 17–42.

Shapley, D., 1977. Will fertilizers harm ozone as much as SST's? Science 195, 658–659.

Shaw, E. G., 1989. Arctic haze. In: Huntzinger, O. (Ed.), Environmental Chemistry. Vol. 4. Springer-Verlag: Berlin, pp. 70–110.

Shaw, G. E., 1975. The vertical distribution of tropospheric aerosols at Barrow, Alaska. Tellus 27 (1), 39–50.

Shaw, G. E., 1982. Evidence for a central Eurasian source area of Arctic haze in Alaska. Nature 299, 815–818.

Shaw, G. E., 1995. The Arctic haze phenomenon. Bulletin of the American Meteorological Society 76 (12), 2403–2413.

Shaw, G. E., Stamnes, K., 1980. Arctic haze: Perturbation of the polar radiation budget. Annals of the New York Academy of Sciences 338 (1), 533–539.

Shepherd, J., 2009. Geoengineering the Climate: Science, Governance and Uncertainty. Royal Society: London.

Sheridan, P., Musselman, I., 1985. Characterization of aircraft-collected particles present in the Arctic aerosol; Alaskan Arctic, spring 1983. Atmospheric Environment (1967) 19 (12), 2159–2166.

Sheridan, P. J., Zoller, W. H., 1989. Elemental composition of particulate material sampled from the Arctic haze aerosol. Journal of Atmospheric Chemistry 9 (1-3), 363–381.

Shifrin, N., Toole, A. P., 1998. Historical perspective on PCBs. Environmental engineering Science 15 (3), 247–257.

Shukla, J., Nobre, C., Sellers, P., 1990. Amazon deforestation and climate change. Science 247 (4948), 1322–1325.

Siddiqui, M., Srivastava, S., Mehrotra, P., Mathur, N., Tandon, I., 2003. Persistent chlorinated pesticides and intra-uterine foetal growth retardation: A possible association. International archives of occupational and environmental health 76 (1), 75–80.

Sinclair, P. C., 1974. Vertical transport of desert particulates by dust devils and clear thermals. Tech. rep., California Univesity, Livermore (USA). Lawrence Livermore Lab.

Skodvin, T., 2000. The ozone regime. In: Wettestad, S. A. T. S. A. U. J. (Ed.), Science and Politics in International Environment Regimes. Manchester University Press: Manchester, pp. 122–146.

Smith, D., 1999. Worldwide trends in DDT levels in human breast milk. International Journal of Epidemiology 28 (2), 179–188.

Smith, T. M., Smith, R. L., 2009. Ökologie. Pearson Deutschland: Hallbergmoos.

Snidal, D., 1985. The game theory of international politics. World Politics 38 (01), 25–57.

Sohár, J., Domoki, J., 2001. Contamination of food and agro products in Hungary. Arhiv za higijenu rada i toksikologiju 52 (2), 163–168.

Soroos, M., 1992. The odyssey of Arctic haze toward a global atmospheric regime. Environment: Science and Policy for Sustainable Development 34 (10), 6–27.

Sprinz, D., Vaahtoranta, T., 1994. The interest-based explanation of international environmental policy. International Organization 48 (01), 77–105.

Sprinz, D. F., Helm, C., 1999. The effect of global environmental regimes: A measurement concept. International Political Science Review 20 (4), 359–369.

Stephens, B. B., Gurney, K. R., Tans, P. P., Sweeney, C., Peters, W., Bruhwiler, L., Ciais, P., Ramonet, M., Bousquet, P., Nakazawa, T., et al., 2007. Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric co2. Science 316 (5832), 1732–1735.

Stern, N. N. H., 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press: Cambridge.

Stocks, B. J., Fosberg, M., Lynham, T., Mearns, L., Wotton, B., Yang, Q., Jin, J., Lawrence, K., Hartley, G., Mason, J., et al., 1998. Climate change and forest fire potential in Russian and canadian boreal forests. Climatic Change 38 (1), 1–13.

Stoel, T. B., Compton, R. I., Gibbons, S. M., 1977. International regulation of chlorofluoromethanes. Environmental Policy and Law 3 (3), 129–132.

Stoel, T. B., Miller, A. S., Milroy, B., 1980. Fluorocarbon Regulation: An International Comparison. Lexington Books: Lanham.

Strange, S., 1982. Cave! hic dragones: A critique of regime analysis. International Organization 36 (02), 479–496.

Tanabe, S., Hidaka, H., Tatsukawa, R., 1983. PCBs and chlorinated hydrocarbon pesticides in antarctic atmosphere and hydrosphere. Chemosphere 12 (2), 277–288.

Tatton, J., Ruzicka, J., 1967. Organochlorine pesticides in Antarctica. Nature 215, 346–348.

Taylor, P. R., Stelma, J. M., E, L. C., 1989. The relation of polychlorlnated biphenyls to birth weight and gestational age in the offspring of occupationally exposed mothers. American Journal of Epidemiology 129 (2), 395–406.

Thrift, C., Wilkening, K., Myers, H., Raina, R., 2009. The influence of science on canada's foreign policy on persistent organic pollutants (1985-2001). Environmental Science & Policy 12 (7), 981–993.

Tsay, S.-C., Stamnes, K., Jayaweera, K., 1989. Radiative energy budget in the cloudy and hazy Arctic. Journal of the Atmospheric Sciences 46 (7), 1002–1018.

Tsydenova, O. V., Sudaryanto, A., KajiWara, N., Kunisue, T., Batoev, V. B., Tanabe, S., 2007. Organohalogen compounds in human breast milk from republic of Buriatia, Russia. Environmental Pollution 146 (1), 225–232.

Turco, R., Whitten, R., Poppoff, I., Capone, L., 1978. SSTs, nitrogen fertilizer and stratospheric ozone. Nature 276, 805 – 807.

Turtle, E., Taylor, A., Wright, E., Thearle, R., Egan, H., Evans, W., Soutar, N., 1963. The effects on birds of certain chlorinated insecticides used as seed dressings. Journal of the Science of Food and Agriculture 14 (8), 567–577.

UN, 2001. Report on the organizational and first sessions. Tech. rep., United Nations.

UN.CSD, 1995. E/cn.17/1995/5: Rewiew of sectoral clusters. Tech. rep., UN Economic and Social Council.

Underdal, A., 2000. Science and politics: The anatomy of an uneasy relationship. In: Science and Politics in International Environmental Regimes. Manchester University Press: Manchester, pp. 1–22.

Underdal, A., 2002. Patterns of regime effectiveness. In: Miles, E. L., Underdal, A., Andresen, S., Wettestad, J., Skiaerset, J. B., Carlin, E. M. (Eds.), Environmental Regime Effectiveness: Confronting Theory with Evidence. MIT Press, Cambridge, pp. 405–435.

Underdal, Arild Young, O. R. (Ed.), 2004. Regime Consequences: Methodological Challenges and Research Strategies. Kluwer Academic Publication: New York.

UN.ECE, 1994a. Eb.air/wg.6/r.20/add.1: Draft executive summary of the state of knowledge report of the task force on persistent organic pollutants led by canada and sweden. Tech. rep., UN-ECE, working Group on Technology.

UN.ECE, 1994b. State of Knowledge Report of the UN ECE Task Force on Persistent Organic Pollutants: For the Convention on Long-range Transboundary Air Pollution: for Presentation to the Meetings of the Working Groups on Technology and on Effects 28 June - 1 July, 1994, Geneva. Department of Indian Affairs and Northern Development Canada. Environmental Services and Research Division.

UN.ECE, 1995. Eb.air/wg.5/r.60: Informal plan meeting of the extended bureau of the ad hoc preparatory working group on persistent organic pollutants. Tech. rep., UN. ECE.

UN.ECE, 1997. Eb.air/wg.5/40: Report of the nineteenth session. Tech. rep., UN.ECE.

UNEP, 1996. Information on persistent organic pollutants: Hungary.
URL http://www.chem.unep.ch/pops/indxhtms/oheur3.html

UNEP, 5 2013.
URL www.pops.int

UN.ESC, 1999. E/cn.17/iff/1999/25: Report of the intergovernmental forum on forests on its third session. Tech. rep., United Nations.

Unge, M., Kiær, H., Blichert-Toft, M., Olsen, J., Clausen, J., 1984. Organochlorine compounds in human breast fat from deceased with and without breast cancer and in a biopsy material from newly diagnosed patients undergoing breast surgery. Environmental Research 34 (1), 24–28.

Veljanoska-Sarafiloska, E. M., Jordanoski, M., Stafilov, T., 2013. Presence of DDT metabolites in water, sediment and fish muscle tissue from lake prespa, republic of macedonia. Journal of Environmental Science and Health, Part B 48 (7), 548–558.

Voldner, E. C., Li, Y.-F., 1995. Global usage of selected persistent organochlorines. Science of The Total Environment 160 (0), 201 – 210.

Waltz, K. N., 2001. Man, the State, and War: A theoretical Analysis. Columbia University Press: New York.

Wania, F., Mackay, D., 1993. Global fractionation and cold condensation of low volatility organochlorine compounds in polar regions. Ambio 22 (1), 10–18.

Wania, F., Mackay, D., 1996. Tracking the distribution of persistent organic pollutants. Environmental Science & Technology 30 (9), 390–396.

Warren, S. G., Wiscombe, W. J., 1980. A model for the spectral albedo of snow. ii: Snow containing atmospheric aerosols. Journal of the Atmospheric Sciences 37 (12), 2734–2745.

Wassermann, M., Nogueira, D., Tomatis, L., Mirra, A., Shibata, H., Arie, G., Cucos, S., Wassermann, D., 1976. Organochlorine compounds in neoplastic and adjacent apparently normal breast tissue. Bulletin of Environmental Contamination and Toxicology 15 (4), 478–484.

Wendling, P., Wendling, R., Renger, W., Covert, D., Heintzenberg, J., et al., 1985. Calculated radiative effects of Arctic haze during a pollution episode in spring 1983 based on ground-based and airborne measurements. Atmospheric Environment (1967) 19 (12), 2181–2193.

Wendt, A., 1992. Anarchy is what states make of it: The social construction of power politics. International Organization 46 (02), 391–425.

Westoby, J. C., 1989. Introduction to World Forestry, 1st Edition. Basil Blackwell, Oxford.

Wettestad, J., 2000. The ece convention on long-range transboundary air pollution: from common cuts to critical loads. In: Wettestad, S. A. T. S. A. U. J. (Ed.), Science and Politics in International environmental Regimes: Between integritiy and involvement. Manchester University Press: Manchester, pp. 95–121.

Wharton, R., Reid, J., 1950. DDT and gammexaneas residual insecticides against anopheles maculatus in malaya. Science 165, 28–29.

Wheatley, G., Hardman, J., 1965. Indications of the presence of organochlorine insecticides in rainwater in central England. Nature 207, 486–487.

Whitten, R., Borucki, W., Capone, L., Riegel, C., Turco, R., 1980. Nitrogen fertiliser and stratospheric ozone: Latitudinal effects. Nature 283 (5743), 191–192.

WHO, 1979. DDT and its Derivatives. World Health Organization.

WHO, 2000. Interlaboratory quality assessment of levels of PCBs, pcdds and pcdfs in human milk and blood plasma: fourth round of who-coordinated study. Tech. rep., World Health Organization.

Wickström, K., Pyysalo, H., Siimes, M. A., 1983. Levels of chlordane, hexachlorobenzene, PCB and DDT compounds in Finnish human milk in 1982. Bulletin of environmental contamination and toxicology 31 (3), 251–256.

Wiertz, T., 2011. Klimakontrolle oder klimakatastrophe? gefahren im diskurs um geoengieering. In: Globales Rapa Nui? Frieden und Sicherheit im Zeichen des Klimawandels. Optimus: Goettingen, pp. 258–285.

Wilson, S. J., Murray, J. L., Huntington, H. P., Monitoring, A., 1998. AMAP Assessment Report: Arctic Pollution Issues. Arctic Monitoring and Assessment Programme (AMAP).

Winchester, J. W., Schnell, R. C., Fan, S.-M., Li, S.-M., Bodhaine, B. A., Stuart Naegele, P., Hansen, A., Rosen, H., 1985. Particulate sulfur and chlorine in Arctic aerosols, spring 1983. Atmospheric Environment (1967) 19 (12), 2167–2173.

Wisniewski, J., Trexler, M., Dixon, R.K. Solomon, A., Houghton, R., Brown, S., 1994. Carbon pools and flux of global forest ecosystems. Science 263 (5144), 185–190.

Wolff, M. S., Toniolo, P. G., Lee, E. W., Rivera, M., Dubin, N., 1993. Blood levels of organochlorine residues and risk of breast cancer. Journal of the National Cancer Institute 85 (8), 648–652.

Woods, J., Polissar, L., Severson, R., Heuser, L., Kulander, B., et al., 1987. Soft tissue sarcoma and non-hodgkin's lymphoma in relation to phenoxyherbicide and chlorinated phenol exposure in western washington. Journal of the National Cancer Institute 78 (5), 899.

Woodwell, G. M., Hobbie, J. E., Houghton, R. A., Melillo, J. M., Moore, B., Peterson, B. J., Shaver, G. R., 1983. Global deforestation: Contribution to atmospheric carbon dioxide. Science 222 (4628), 1081–1086.

Young, M., Schafer, M., 1998. Is there method in our madness? Ways of assessing cognition in international relations. Mershon International Studies Review 42 (1), 63–96.

Young, O. R., 1989. The politics of international regime formation: Managing natural resources and the environment. International Organization 43 (2), 349–375.

Young, O. R., 1991. Political leadership and regime formation: On the development of institutions in international society. International Organization 45 (3), 281–308.

Young, O. R., 1993. Polar Politics: Creating International Environmental Regimes. Cornell University Press: Ithaca.

Young, O. R., 1994. International Governance: Protecting the environment in a Stateless society. Cornell University Press: Ithaca.

Young, O. R., 2001. Inferences and indices: Evaluating the effectiveness of international environmental regimes. Global Environmental Politics 1 (1), 99–121.

Zennegg, M., Schmid, P., Vermeirssen, E., Tremp, J., 2013. Old sins throw long shadows: PCBs–40 years after restrictions in switzerland–still an environmental problem? Chimia 57 (9), 509–513.

Zon, R., Sparhawk, W. N., 1923. Forest resources of the world. McGraw-Hill: New York 1 (2), 1.

Zürn, M., 1992. Interessen und Institutionen in der Internationalen Politik: Grundlegung und Anwendungen des situationsstrukturellen Ansatzes. Leske + Budrich: Tübingen, Opladen.

Chapter 7

Appendix A

Country	**Year**	**Source**
Austria	1992	Smith and Smith (2009)
Canada	1972	Pham et al. (1996)
Croatia	1973	Gajski et al. (2012)
Cyprus	no data available	
Czech Republic	1974	Bernek (2005)
Denmark	1984	Schmidt (2001)
Estonia	1964	Roots et al. (2008)
Finland	1977	Wickström et al. (1983)
France	1973	Lemarchand et al. (2007)
Germany	1974	Frank et al. (2007)
Greece	1972	Goutner et al. (1997)
Hungary	1969	UNEP (1996)
Iceland	Never in use	
Ireland	1985	UNEP (1996)
Italy	1978	Dommarco et al. (1987)
Latvia	1968	UNEP (1996)
Lichtenstein	no data available	
Lithuania	1970	Petraitis et al. (2013)
Luxembourg	1988	Pacyna et al. (2003)
Macedonia	1982	Veljanoska-Sarafiloska et al. (2013)
Moldova	no data available	
Netherlands	1968	Opdam et al. (1987)
Norway	1970	Kveseth et al. (1979)
Poland	1989	Ludwicki and Góralczyk (1994)
Portugal	no data available	
Romania	1987	Covaci et al. (2001)
Slovakia	1974	Petrik et al. (2006)
Spain	1972	Hernandez et al. (1986)
Sweden	1969	Olsson and Reutergårdh (1986)
Switzerland	1972	Bogdal et al. (2008)
Ukraine	1994	Kuznyetsov (2008)
UK	1984	Dryzek et al. (2003)
USA	1972	(Hinck et al., 2009)

TABLE 7.1: Domestic Regulation of DDT

Country	**Year**	**Source**
Austria	no data available	
Bulgaria	1980s	Dimitrova et al. (2011)
Canada	1977	Ross (2006)
Croatia	no data available	
Cyprus	1987	Ministry of Labour and Social Insurance (2007)
Czech Republic	1979	Pulkrabová et al. (2009)
Denmark	1986	UNEP (2013)
Estonia	1999	UNEP (2013)
Finland	1998	UNEP (2013)
France	1987	Brucker-Davis et al. (2008)
Germany	1972	UNEP (2013)
Greece	1970s	Konstantinou et al. (2000)
Hungary	1979s	Sohár and Domoki (2001)
Iceland	no data available	
Ireland	no data availlable	
Italy	1970s	Naso et al. (2005)
Latvia	2002	www.pops.int
Lichtenstein	no data available	
Lithuania	1999	UNEP (2013)
Luxembourg	no data available	
Macedonia		no data availble
Moldova	no data available	
Netherlands	1970s	Canters and De Snoo (1993)
Norway	1981	Marthinsen et al. (1991)
Poland	1996	UNEP (2013)
Portugal	no data available	
Romania	no data available	
Slovakia	1980s	Petrik et al. (2006)
Spain	1976	Arrebola et al. (2010)
Sweden	1986	UNEP (2013)
Switzerland	1986	Zennegg et al. (2013)
Ukraine		
UK	1981	Law et al. (2010)
USA	1977	Hartmann et al. (2005)

Table 7.2: Domestic Regulation of PCBs

Country	PCBs-Emissions in 1970	PCBs-Emissions in 1996	ΔPCB(t) 1970 – 1996	Year of Regulation
Armenia	n/a	n/a	n/a	n/a
Austria	38010	1368	- 36607	n/a
Bulgaria	186	518	+332	1980s
Canada	n/a	n/a	n/a	1977
Croatia	n/a	n/a	n/a	n/a
Cyprus	n/a	n/a	n/a	1987
Czech Republic	507	762	+259	1979
Denmark	24971	1026	- 23945	1986
Estonia	86	135	+49	1999 (www.pops.int)
Finland	23451	2721	- 20730	1998
France	258091	2037	- 237744	1987
Germany	402160	42462	- 359698	1972
Greece	17936	221	- 17715	1970s
Hungary	180	554	+374	1970s
Iceland	n/a	n/a	n/a	n/a
Ireland	6013	77	- 5936	n/a
Italy	270757	6054	- 264703	1970s
Latvia	28	126	+98	2002
Lichtenstein	n/a	n/a	n/	n/a
Lithuania	24	178	+154	1999
Luxembourg	2060	127	- 1933	n/a
Macedonia	n/a	n/a	n/a	n/a
Moldova	22	206	+184	n/a
Netherlands	65823	250	- 565573	1970s
Norway	19598	408	- 19190	1981
Poland	637	2374	+1737	1996
Portugal	18171	557	- 17614	n/a
Romania	194	1218	+11024	n/a
Russian Federation	2094	8072	+5978	1992
Slovakia	n/a	n/a	n/a	1980s
Slovenia	n/a	n/a	n/a	n/a
Spain	170541	8721	- 161820	1976
Sweden	41163	2022	- 39141	1986
Switzerland	n/a	n/a	n/a	1986
Ukraine	1181	3043	+1862	1986
UK	282443	3706	- 278737	1981
USA	114000	0	- 114000 [1]	1977
SUM	**2308834**	**119121**	**- 2189713**	

TABLE 7.3: Change in PCBs Emissions between 1970 and 1996 in Signatory States and Russia

Emission Data predominantly rests on the following sources: Breivik et al. (2004); Pacyna et al. (2003); Pacyna (1999).

Scientific Contributions on Perstitent Organic Pollutants

Title	Author	Year	Journal	Citations
Site of Action of D.D.T. and Cause of Death after Acute D.D.T. Poisoning	D.Dresden	1948	Nature	10
Susceptibility of DDT-resistant Houseflies to Other Insecticidal Sprays	H. Wilson	1948	Science	17
Persistence of D.D.T. and Benzene Hexachloride in Soil	Smith	1948	Nature	22
Effect of Cooking on the DDT Content of Beef	B. CARTER	1948	Science	22
A Theory of Herbicidal Action	A. Crafts	1948	Science	32
Development of a Strain of Houseflies Resistant to DDT	A. Linquist	1948	Science	38
Reversible Action of D.D.T.	H. Hurst	1949	Nature	13
D.D.T.-Resistance in Houseflies in Denmark	J. Keiding	1949	Nature	15
Lepidopterous Eggs and Larvæ from the Exterior of Aircraft Fuselages	M. Laird	1950	Nature	2
Stability of the Adenosinetriphosphatase System in Animal Tissues	M. Marquette	1950	Science	4
Determination of DDT by Bioassay	C. Pagan	1950	Science	4
Cross Tolerances in Resistant Houseflies	J. Pratt	1950	Science	6
Development and Viability of *Drosophila melanogaster* on a Medium Containing DDT	B. Kalina	1950	Science	9
D.D.T. and 'Gammexane' as Residual Insecticides against Anopheles maculatus in Malaya	R. Wharton	1950	Nature	16
Insecticidal Action of DDT	E. Skerrett	1950	Nature	32
The Detoxification of DDT by Resistant Houseflies and Inhibition of This Process by Piperonyl Cyclonene	A. Perry	1950	Science	71
Fat Deposits in the Kidney in Chronic Intoxication of the Dog by Hexachlorocyclohexane	M. Dallemagne	1950	Science	114
Houseflies Resistant to Benzene Hexachloride	J. Gahan	1950	Science	204
DDT as a Residual Insecticide against A. letifer and A. maculatus in Malaya	C. Nair	1951	Nature	2
Synergistic Action of DDT and BHC Combined Sprays	R.Pal	1951	Nature	2
DDT and BHC as Residual Insecticides in Malaya	R. Wharton	1951	Nature	4
Effects of DDT upon Different Species of Mosquitoes in Malaya	J. Reid	1951	Nature	5
Fly Reactions to Insecticidal Deposits: a New Test Technique	F. Baranyovits	1951	Nature	9
Malaria Eradication Scheme, Mauritius	C. Dowling	1951	Nature	15
The Resistance of DDT-resistant Drosophila to Other Insecticides	R. Weiner	1951	Science	18
Duration of Action of Residual DDT Deposits on Adobe Surfaces	W. Downs	1951	Science	24
Sorption of Solid Insecticides by Dried Mud	A. Hadaway	1951	Nature	26
Inheritance of Resistance to DDT in the Housefly, Musca domestica L.	C. Harrison	1951	Nature	31
Resistance of Houseflies to Ddt	F. Winteringham	1951	Nature	43
Mechanism of Resistance to Insecticide in Houseflies	J. Busvine	1951	Nature	197

Phosphorus as a Factor Preventing DDT-Dehydrochlorination	H. Maes	1952	Nature	3
Effects of House Spraying on African Anophelines	P. Wilkinson	1952	Nature	4
Inactivation of DDT by Soils	A. Hadaway	1952	Nature	5
Lipoid Solubility as a Factor in the Toxicity of Contact Insecticides	S Pradhan	1952	Nature	16
Examination of Human Fat for the Presence of DDT	G. Pearce	1952	Science	25
Selection for DDT Resistance in a Beneficial Insect Parasite	D. Pielou	1952	Science	36
DDT Resistance in Korean Body Lice	H. Hurlut	1952	Science	53
Insect Resistance to Insecticides	R. Beard	1952	Science	95
Microanatomical Study of DDT-moribund Anopheles quadrimaculatus Say	J. Jones	1953	Science	2
Effects of DDT and BHC on Soil Arthropods	J. Sheals	1953	Nature	5
Synergistic Actions of Carbon Dioxide with DDT in the Central Nervous System	G. Pollock	1953	Science	12
Amount of Gamma-Benzene Hexachloride picked up by Resistant Houseflies bred on a Medium containing Benzene Hexachloride	F. Bradbury	1953	Nature	19
DDT Detoxification Product in American Cockroaches	J. Butts	1953	Science	19
Adsorption of DDT on Suspended Solids in River Water and its Role in Black-fly Control	F. Fredeen	1953	Nature	31
Forms of Insecticide-Resistance in Houseflies and Body Lice	J. Busvine	1953	Nature	56
Toxic Chemicals in Agriculture and their Effect on Foodstuffs	F. Aylward	1954	Nature	1
Occurrence of Dieldrin-resistance in Wild Musca domestica L. in England	K. Goodwin	1954	Nature	6
Effect of DDT on the Metabolism of Khapli Wheat Seedlings	F. Forsyth	1954	Nature	8
Metabolism of Gamma-Benzene Hexachloride in Susceptible and Resistant Houseflies	F. Oppenorth	1954	Nature	17
Houseflies Resistant to a Group of Chlorinated Hydrocarbon Insecticides	J. Busvine	1954	Nature	56
A New Group of DDT Synergists	E. Bergmann	1955	Nature	12
Differences between Rates of Metabolism of Benzene Hexachloride in Resistant and Susceptible Houseflies	F. Oppenorth	1955	Nature	14
Effect of Arasan-Treated Corn on Laying Hens	P. Waibel	1955	Science	15
Effect of DDT on Enzymatic Oxidation and Phosphorylation	J. Sacklin	1955	Science	25
A Case of DDT Poisoning in Fish	E. Burden	1956	Nature	11
Cumulative Effect of Sub-Lethal Doses of Insecticides on Houseflies	A. Hadaway	1956	Nature	17
Dehydrochlorination of DDT by Resistant Houseflies and Mosquitoes	A. Brown	1956	Nature	20
Effect of DDD and Some of Its Derivatives on Plasma 17-OH-Corticosteroids in the Dog	F. Cobey	1956	Science	20
Insecticide Resistance in Anopheles gambiae Giles	G. Davidson	1956	Nature	33
Insecticide Resistance in Anopheles gambiae Giles	R. Elliot	1956	Nature	34
Effect of Changes in Humidity on the Toxicity and Distribution of Insecticides sorbed by some Dried Soils	F. Barlow	1956	Nature	44
Normal Resistance-level of Anopheles funestus Giles to Insecticides	R. Elliot	1957	Nature	4
Improved Persistence of Dieldrin Deposits on Sorptive Mud Surface	P. Gerolt	1957	Nature	7
Specific DDT-Resistance in Houseflies	R. Kerr	1957	Nature	15
Effect of DDT on Egg-laying by Oscinella frit L.	T. Legowski	1958	Nature	1

Laboratory Variations in Mortality of the Mosquito, Culex fatigans Wied., exposed to DDT	T. Koshi	1958	Nature	2
Dosage–Mortality Curves for Houseflies Susceptible and Resistant to DDT	P. Hewlett	1958	Nature	3
Effects of Simulium Control on Insectivorous Fishes	P. Corbet	1958	Nature	6
A New Type of Insecticide	Z. Ogita	1958	Nature	12
Influence of DDT and Lindane on Chordotonal Organs in the Cockroach	G. Becht	1958	Nature	30
'Vapour Toxicity' of Solid Insecticides	P. Gerolt	1959	Nature	6
Varietal Resistance to Spray Damage in Barley	J. Hayes	1959	Nature	33
Metabolism of Benzene Hexachloride by Resistant Houseflies Musca domestica	F. Bradbury	1959	Nature	57
Selection for High-Order Resistance to 'Dieldrin' in Lucilia cuprina Wied.	G. Shanahan	1960	Nature	2
Influence of Dietary Intake of Certain Insecticides on the Hæmoglobin and Erythrocyte Contents of Chick Blood	B. Sricastava	1960	Nature	6
Effect of DDT on Free Amino Acids of Susceptible and DDT-Resistant Aedes aegypti Larvae	D. Micks	1960	Science	6
Sex-limited DDT-Resistance in House-flies	R. Kerr	1960	Nature	18
Some Effects of Aldrin and DDT on the Soil Fauna of Arable Land	C. Edwards	1960	Nature	25
Allelic Genes in the Housefly Producing Modified Enzymes That Cause Organophosphate Resistance	F. Oppenoorth	1960	Science	156
Resistance to Dieldrin in Anopheles in Trinidad	T. Omardeen	1961	Nature	1
Effect of Age and Pregnancy on the Tolerance of Tsetse Flies to Insecticides	G. Burnett	1961	Nature	10
Insecticide Resistance in Mosquitoes	G. Davidson	1961	Nature	16
Multi-Resistant Aedes aegypti in Puerto Rico and Virgin Islands	I. Fox	1961	Science	24
Insecticide Content of Diet and Body Fat of Alaskan Natives	W. Durham	1961	Science	115
Effect of 'Rogor' (Dimethoate) and DDT on Cotton Mites in Uganda	W. Ingram	1962	Nature	5
Houseflies Resistant to Organic Phosphate in Australia	R. Hart	1962	Nature	7
Influence of Relative Humidity on the Uptake of Insecticides from Residual Films	P. Gerolt	1962	Nature	10
Insecticide Resistance: Effects of WARF Antiresistant on Toxicity of DDT to Adult Houseflies	D. Spiller	1963	Science	3
Effects of p-Dimethylaminoazobenzene on the Fine Structure of Rat Liver Cells	A. Timme	1963	Nature	8
Insecticide Resistance in the Cocoa Capsid, Distantiella theobroma (Dist.)	J. Dunn	1963	Nature	14
Dieldrin Susceptibility: Partial Restoration in Anopheles Selected with a Carbamate	G, Georghiou	1963	Science	20
Insecticide Resistance in the Cabbage Root Fly in Britain	T. Coaker	1963	Nature	21
DDT and Dieldrin in Rivers: A Report of the National Water Quality Network	A. Breidenbach	1963	Science	48
Insecticides: Effects on Cutthroat Trout of Repeated Exposure to DDT	D. Allison	1963	Science	58
Storage of Insecticides in French People	J. Hayes	1963	Nature	60
Resistance to DDT in the Mosquito Fish, Gambusia affinis	S. Bradleight	1963	Science	64
Chlorinated Insecticides in the Body Fat of People in the United States	W. Dale	1963	Science	105
Poisoning by DDT: Relation between Clinical Signs and Concentration in Rat Brain	W. Dale	1963	Science	112
Effects of Low-temperature Storage on the Eggs of Spodoptera littoralis (Boisd.)	N. Hussey	1964	Nature	5
Ingestion of DDT and Liver Glucose-6-phosphate Dehydrogenase Activity	I. Tinsley	1964	Nature	14

Insecticide Sevin: Effect of Aerial Spraying on Drift of Stream Insects	C. Coutant	1964	Science	27
Bats: Sensitivity to DDT	M. Luckens	1964	Science	33
Influence of Soil Type and Soil Moisture on the Toxicity of Insecticides in Soils to Insects	C. Harris	1964	Nature	35
Persistence of DDT in Soils of Heavily Sprayed Forest Stands	G. Woodwell	1964	Science	36
Toxic Residues in Soil 9 Years after Treatment with Aldrin and Heptachlor	A. Wilkinson	1964	Science	40
Conversion of p,p' DDT to p,p' DDD in the Liver of the Rat	P. Detta	1964	Science	42
DDT: A New Hypothesis of Its Mode of Action	R. Brien	1964	Science	42
Role of DDT-hydroxylation in Resistance	A. Morello	1964	Nature	43
Chlorinated Insecticides: Fate in Aqueous Suspensions Containing Mosquito Larvae	M. Bowman	1964	Science	45
DDT Antagonism to Dieldrin Storage in Adipose Tissue of Rats	J. Street	1964	Science	82
Organic Chlorine Insecticide Residues in Wild Birds	N. Moore	1964	Nature	83
DDT Spray and Bird Mortality	I. McDeal	1965	Science	1
Bird Mortality after Spraying for Dutch Elm Disease with DDT	C. Wurster	1965	Science	36
DDT-metabolism in Resistant and Susceptible Stable-flies and in Bacteria	J. Stenersen	1965	Nature	51
DDT in Human Milk	G. Quinby	1965	Nature	75
Organochlorine Pesticides in the Atmospheric Environment	D. Abbot	1965	Nature	76
Conversion of DDT to DDD by Proteus vulgaris, a Bacterium isolated from the Intestinal Flora of a Mouse	P. Baker	1965	Nature	81
Indications of the Presence of Organochlorine Insecticides in Rainwater in Central England	G. Weatley	1965	Nature	94
Increases in the Incidence of Atherigona indica infuscata Emden Diptera (Anthomyiidae) on Sorghum due to Spraying	J. Davies	1966	Nature	14
Pesticide Residues in the Irish Environment	J. Eades	1966	Nature	17
Organochlorine Insecticide Residues in Complete Prepared Meals in Great Britain during 1965	J. Robinson	1966	Nature	17
Endrin: Use of Concentration in Blood To Diagnose Acute Toxicity to Fish	D. Mount	1966	Science	21
Organochlorine Insecticide Residues in Soil Invertebrates	B. Navis	1966	Nature	23
Effect of Some Insecticides on the Hatching Rate of Hens' Eggs	J. Dunachie	1966	Nature	23
Dieldrin: Interaction with Nerve Components of Cockroaches	F. Masumura	1966	Science	29
In vitro Metabolism of p,p’DDT in Pigeon Liver	P. Bunyan	1966	Nature	33
Uptake of pp’-DDT and its Post-mortem Breakdown in the Avian Liver	D. Jefferies	1966	Nature	68
Pesticide Residues in Total-Diet Samples	L. Gould	1966	Science	74
Biodegradation of the Gamma Isomer of Benzene Hexachloride in Submerged Soils	K. Raghu	1966	Science	78
Residues of DDT in Brains and Bodies of Birds That Died on Dosage and in Survivors	L. Stickel	1966	Science	83
Chlorinated Hydrocarbon Pesticides: Degradation by Microbes	C. Cehacko	1966	Science	130
DDT Residues in Adelie Penguins and A Crabeater Seal from Antarctica	W. Sladen	1966	Nature	182
Detection and Measurement of Pesticide Residues	D. Lisk	1966	Science	271
Effect of DDT on Photosynthesis in Certain Varieties of Barley	P. Lawler	1967	Nature	20
Variations dependent on Age and Diet in the Metabolism of 7,12-Dimethylbenz[a]-anthracene by Rat Liver Homogenates	P. Sims	1967	Nature	21

Danger of Chlorinated Hydrocarbon Insecticides in Birds' Eggs	J. Koeman	1967	Nature	31
Poisonig with DDT: Effect on Reproductive Performance of Artemia	D. Grosh	1967	Science	40
Dynamics of Organochlorine Insecticides in Vertebrates and Ecosystems	J. Robinson	1967	Nature	45
Spruce Budworm Mortality as a Function of Aerial Spray Droplet Size	C. Himel	1967	Science	48
Endrin Resistance in the Pine Mouse	R. Webb	1967	Science	50
Dietary Intake of Pesticide Chemicals	R. Duggan	1967	Science	56
DDT Residues in Pacific Sea Birds: a Persistent Insecticide in Marine Food Chains	E. Risebrough	1967	Nature	91
Metabolism of Methylcarbamate Insecticides by the NADPH2-requiring Enzyme System from Houseflies	M. Tsukamoto	1967	Nature	94
DDT: Interaction with Nerve Membrane Conductance Changes	T. Narahashi	1967	Science	99
Organochlorine Pesticides in Antarctica	J. Tatto	1967	Nature	119
Anaerobic Biodegradation of DDT to DDD in Soil	W. Guenzi	1967	Science	122
Organochlorine Residues in Marine Organisms	J. Robinson	1967	Nature	126
Pesticide Pollution Control	H. Nicholson	1967	Science	131
Chlorinated Hydrocarbons in British Wildlife	D. Holmes	1967	Nature	149
Organochlorine Pesticides in Seals and Porpoises	A. Holden	1967	Nature	172
Pesticide-induced Enzyme Breakdown of Steroids in Birds	D. Peakall	1967	Nature	180
Persistence of Chlorinated Hydrocarbon Insecticides in Soils	R. Nash	1967	Science	209
DDT Residues in an East Coast Estuary: A Case of Biological Concentration of a Persistent Isecticide	G. Woodwell	1967	Science	299
Decrease in Eggshell Weight in Certain Birds of Prey	D. Rattcliffe	1967	Nature	717
Relation between DDT in Diets of Laying Birds and Viability of their Eggs	F. Jones	1968	Nature	10
Success of Eggs of the Shag on the Farne Islands, Northumberland, in relation to their Content of Dieldrin and pp' DDE	G. Potts	1968	Nature	42
DDT Residues and Declining Reproduction in the Bermuda Petrel	C. Wurster	1968	Science	100
Organochlorine Pesticides in Rainwater in the British Isles	K.Tarrant	1968	Nature	118
DDT Reduces Photosynthesis by Madne Phytoplankton	C. Wurster	1968	Science	202
Pesticides: Transatlantic Movements in the Northeast Trades	R. Risebrough	1968	Science	206
Estrogenic Activity of o, p'-DDT in the Mammalian Uterus and Avian Oviduct	J. Bitman	1968	Science	246
Chlorinated Hydrocarbons and Eggshell Changes in Raptorial and Fish-Eating Birds	J. Hickey	1968	Science	501
Polychlorinated Biphenyls in the Global Ecosystem	R. Risebrough	1968	Nature	776
Residues of Dieldrin (HEOD) in Complete Prepared Meals in Great Britain during 1967	J. Robinson	1969	Nature	10
Effect of DDT on Calcium Uptake and Vitamin D Metabolism in Birds	D. Peakall	1969	Nature	28
Degradation and Disappearance of ortho, para Isomer of Technical DDT in Living and Dead Avian Tissues	M. French	1969	Science	35
Dieldrin and Eggshell Thickness in Ducks	P. Lehner	1969	Nature	45
Persistence of DDT in Wild Populations of Small Mammals	J. Dimond	1969	Nature	47
Induction of Apparent Hyperthyroidism in Birds fed DDT	D. Jefferies	1969	Nature	47
DDT: Sublethal Effects on Brook Trout Nervous System	J. Anderson	1969	Science	65

DDT Residues Absorbed from Organic Detritus by Fiddler Crabs	W. Odum	1969	Science	82
DDT in Antarctic Snow	T. Peterle	1969	Nature	109
Adenosine Triphosphatase Sensitive to DDT in Synapses of Rat Brain	F. Masumura	1969	Science	114
DDT induces a Decrease in Eggshell Calcium	J. Bitman	1969	Nature	146
Dieldrin and DDT: Effects on Sparrow Hawk Eggshells and Reproduction	R. Porter	1969	Science	183
Chlorinated Biphenyls in Fish, Mussels and Birds from the River Rhine and the Netherlands Coastal Area	J. Koeman	1969	Nature	319
DDT and PCB in Marine Animals from Swedish Waters	S. Jensen	1969	Nature	583
Insect Control: Alternatives to the Use of Conventional Pesticides	R. Holcomb	1970	Science	5
DDT Metabolism: Oxidation of the Metabolite 2,2-bis(p-Chlorophenyl) ethanol by Alcohol Dehydrogenase	J. Suggs	1970	Science	11
In Vitro Conversion of DDT to DDD by the Intestinal Microflora of the Northern Anchovy, Engraulis mordax	T. Malone	1970	Nature	24
Effect of DDT on the Nursing Neonate	M. Fahim	1970	Nature	26
DDT Residues in Marine Phytoplankton: Increase from 1955 to 1969	J. Cox	1970	Science	41
Antagonism by DDT of the Effect of Valinomycin on a Synthetic Membrane	B. Hilton	1970	Science	47
Chlorinated Hydrocarbon Insecticides: Root Uptake versus Vapor Contamination of Soybean Foliage	R. Nash	1970	Science	52
Photooxidation of DDT and DDE	J. Plimmer	1970	Science	69
DDT Metabolites and Analogs: Ring Fission by Hydrogenomonas	D. Focht	1970	Science	73
Systems Studies of DDT Transport	H. Harrison	1970	Science	88
Metabolic Effects of Polychlorinated Biphenyls in the American Kestrel	J. Linger	1970	Nature	91
DDT-Induced Inhibition of Avian Shell Gland Carbonic Anhydrase: A Mechanism for Thin Eggshells	J. Bitman	1970	Science	94
Marine Phytoplankton Vary in Their Response to Chlorinated Hydrocarbons	D. Menzel	1970	Science	152
p,p'-DDT: Effect on Calcium Metabolism and Concentration of Estradiol in the Blood	D. Peakall	1970	Science	158
DDE thins Eggshells of Captive American Kestrels	S. Wiemeyer	1970	Nature	166
Decay Time of DDT	S. Bloom	1971	Science	8
Environmental DDT and the Genetics of Natural Populations	L. Cory	1971	Nature	14
Nonconversion of o,p'-DDT to p,p'-DDT in Rats, Sheep, Chickens, and Quail	J. Bitman	1971	Science	14
Effect of PCB on Nocturnal Activity in Caged Robins, Erithacus rubecula L.	S. Ulfstrand	1971	Nature	19
DDT Tissue Retention: Sudden Rise Induced by the Addition of Aldrin to a Fixed DDT Intake	W. Deichmann	1971	Science	22
DDE reduces Medullary Bone Formation in Birds	M Oestreicher	1971	Nature	23
Food Chain Model for DDT Kinetics in a Freshwater Marsh	L. Eberhardt	1971	Nature	30
DDT metabolized by Microorganisms from Lake Michigan	F. Matsumura	1971	Nature	31
Evaporation of DDT	C. Lloyd	1971	Nature	40
Organochlorine Pesticide Residues in Harbour Porpoises from the Bay of Fundy Region	D. Gaskin	1971	Nature	50
DDT Residues: Distribution of Concentrations in Emerita analoga (Stimpson) along Coastal California	R. Burnett	1971	Science	62
Sensitivity of Fish ATPases to Polychlorinated Biphenyls	H. Yap	1971	Nature	64
DDT: Disrupted Osmoregulatory Events in the Intestine of the Eel Anguilla rostrata Adapted to Seawater	R. Janicki	1971	Science	66

DDT in California Sea Lions	Burney	1971	Nature	71
Polychlorinated Biphenyl absorbed from Sediments by Fiddler Crabs and Pink Shrimp	D. Nimmo	1971	Nature	77
Selective Predation by Newts on Frog Tadpoles treated with DDT	A. Cooke	1971	Nature	95
DDT Administered to Neonatal Rats Induces Persistent Estrus Syndrome	W. Heinrichs	1971	Science	109
DDE Residues and Eggshell Changes in Alaskan Falcons and Hawks	T. Cade	1971	Science	166
DDT in the Biosphere: Where Does It Go?	G. Woodwell	1971	Science	322
DDT in British Rain	J. Edwards	1972	Science	2
BHC Not Found to Reduce the Shell Quality of Hens' Eggs	C. Whitehead	1972	Nature	9
Atmospheric Circulation of DDT	C. Stewart	1972	Science	10
Insecticide Resistance in Glasshouse Whitefly	L. Wardlow	1972	Nature	22
Disagreements on Why Brown Pelican Eggs are Thin	W. Hazeltine	1972	Nature	23
Further Analysis of the Logarithmic Relationship of DDE Residues to Eggshell Thinning	L. Blus	1972	Nature	24
Changes in Organochlorine Contamination of the Marine Environment of Eastern Britain monitored by Shag Eggs	J. Coulson	1972	Nature	28
Effects of Polychlorinated Biphenyl on Marine Phytoplankton Communities	S. Moore	1972	Nature	30
Loss of DDT from Storage in Human Body Fat	D. Morgan	1972	Nature	33
Organochlorine Levels in Atlantic Seabirds	J. Bogan	1972	Nature	37
Increased Hepatic Microsomal Enzyme Activity from Occupational Exposure to Certain Organochlorine Pesticides	J. Hunter	1972	Nature	66
Polychlorinated Biphenyl Residues: Accumulation in Cayuga Lake Trout with Age	C. Bach	1972	Science	67
Chlorinated Hydrocarbon Residues in Airborne Fallout	A. Södergren	1972	Nature	71
Evidence of Cross-resistance to a Juvenile Hormone Analogue in Some Insecticide-resistant Houseflies	D. Cerf	1972	Nature	71
Mutagenicity of Dichlorvos	M. Ashwood	1972	Nature	73
Interpretation of Persistence and Effects of Polychlorinated Biphenyls in Birds	S. Bailey	1972	Nature	81
PCB's in the Environment	C. Adler	1972	Science	89
Polychlorinated Biphenyl- and Triphenyl-Induced Gastric Mucosal Hyperplasia in Primates	J. Allen	1972	Science	107
Polychlorinated Biphenyls: Toxicity to Certain Phytoplankters	J. Mosser	1972	Science	112
Logarithmic Relationship of DDE Residues to Eggshell Thinning	L. Blus	1972	Nature	131
Polychlorinated Biphenyls and DDT Alter Species Composition in Mixed Cultures of Algae	J. Mosser	1972	Science	144
DDE in Eggs and Embryos of Brown Pelicans	I. Nisbet	1973	Nature	2
Insect Control (II): Hormones and Viruses	J. Marx	1973	Science	9
Insect Viruses: A New Class of Pesticides	N. Wade	1973	Science	11
DDT: An Unrecognized Source of Polychlorinated Biphenyls	T. Maugh	1973	Science	54
Premature Births in California Sea Lions: Association with High Organochlorine Pollutant Residue Levels	R. DeLong	1973	Science	325
Decline of DDT Residues in Migratory Songbirds	D. Johnston	1974	Science	28
Rate of Uptake of DDT from Soil by Earthworms	C. Edwards	1974	Nature	33
DDE: Its Presence in Peregrine Eggs in 1948	D. Peakall	1974	Science	52

Organochlorine residues, eggshell thinning and hatching success in British sparrowhawks	I. Newton	1974	Nature	62
Deposition of DDE and Polychlorinated Biphenyls in Dated Sediments of the Santa Barbara Basin	W. Hm	1974	Science	70
Mirex: An Unrecognized Contaminant of Fishes from Lake Ontario	K. Kaiser	1974	Science	90
Degradation of p, p'-DDT in Reducing Environments	J. Zoro	1974	Nature	97
Toxaphene Insecticide: A Complex Biodegradable Mixture	J. Casida	1974	Science	114
Chlorinated Hydrocarbons in the Sargasso Sea Atmosphere and Surface Water	T. Bidleman	1974	Science	275
Prolonged eggshell thinning caused by DDE in the duck	D. Peakall	1975	Nature	15
Structure of phenolic metabolites of p,p'-DDE in rat, wild seal and guillemot	G. Sundstöm	1975	Nature	24
Organochlorine residues in Antarctic snow	D. Peel	1975	Nature	50
Chlorinated hydrocarbon pollutants and photosynthesis of marine phytoplankton: a reassessment	A. Clark	1975	Science	59
Bat mortality: pesticide poisoning and migratory stress	K. Geluso	1975	Science	105
Brown pelicans: improved reproduction off the southern California coast	D. Anderson	1975	Science	139
Transfer of chlorinated biphenyls to Antarctica	R. Risebrough	1976	Nature	155
Drinking Water: Health Hazards Still Not Resolved	N. Wade	1977	Science	10
Seveso: The Questions Persist Where Dioxin Created a Wasteland	J. Walsh	1977	Science	13
Public health hazards from electricity-producing plants	J. Neyman	1977	Science	20
Polychlorobornane components of toxaphene: structure-toxicity relations and metabolic reductive dechlorination	M. Saleh	1977	Science	38
Polychlorinated biphenyls: penetration into the deep ocean by zooplankton fecal pellet transport	D. Elder	1977	Science	90
Female-Female Pairing in Western Gulls (*Larus occidentalis*) in Southern California	G. Hunt	1977	Science	169
Flame-retardant additives as possible cancer hazards	A. Blum	1977	Science	248
Structural and biological link between pyrethroids and DDT in new insecticides	G. Holan	1978	Nature	43
Polychlorinated Biphenyls: Transfer from Microparticulates to Marine Phytoplankton and the Effects on Photosynthesis	L. Harding	1978	Science	51
Polychlorinated biphenyls may alter marine trophic pathways by reducing phytoplankton size and production	H. O'Connors	1978	Science	70
Dieldrin-induced mortality in an endangered species, the gray bat (Myotis grisescens)	D. Claerk	1978	Science	80
Unusual response of DDT-resistant houseflies to carbinol analogues of DDT	R. Sawicki	1978	Nature	87
Productivity of ospreys in Connecticut--Long Island increases as DDE residues decline	P. Spitz	1978	Science	97
Kanamycin-resistant Scenedesmus obliquus showing simultaneous resistance to other antibiotics and polychlorinated biphenyls	H. Mahanty	1979	Nature	6
Toxaphene, a complex mixture of polychloroterpenes and a major insecticide, is mutagenic	N. Hooper	1979	Science	79
Identifying environmental chemicals causing mutations and cancer	B. Ames	1979	Science	639
DDT contamination at Wheeler National Wildlife Refuge	T. O'Shea	1980	Science	30
Pheromones: Background and Potential for Use in Insect Pest Control	R. Silverstein	1981	Science	90
Global Transport of Organic Pollutants: Ambient Concentrations in the Remote Marine Atmosphere	E. Atlas	1981	Science	371
DDT-induced feminization of gull embryos	D. Fry	1981	Science	548
Biodegradation of chemicals of environmental concern	M. Alexander	1981	Science	794
Exploring Plant Resistance to Insects	T. Maugh	1982	Science	16

Ban of DDT and subsequent recovery of Reproduction in bald eagles	B. Gier	1982	Science	176
Similar mode of action of pyrethroids and DDT on sodium channel gating in myelinated nerves	H. Vijverberg	1982	Nature	177
Insecticide Resistance: Challenge to Pest Management and Basic Research	L. Brattsten	1986	Science	242
Another DOT connection	R. Sharpe	1995	Nature	110
High Concentrations of Toxaphene in Fishes from a Subarctic Lake	K. Kidd	1995	Science	151
Global distribution of persistent organochlorine compounds	S. Sim	1995	Science	614
Persistent DDT metabolite p,p'–DDE is a potent androgen receptor antagonist	W. Kelce	1995	Nature	1446
Do flame retardants threaten ocean life?	J. Boer	1998	Nature	323
Accumulation of persistent organochlorine compounds in mountains of western Canada	J. Blais	1998	Nature	412
Trans-Pacific Air Pollution	K. Wilkening	2000	Science	193

Sciencentific Contributions on Ozone and CFCs

Title	Author	Year	Journal	Citations
Possible Destruction of Ozone by Volcanic Material at 50 mbar	A. B. Pittcock	1965	Nature	26
Atmospheric halocarbons and stratospheric ozone	Lovelock	1974	Nature	147
Stratospheric sink for chlorofluoromethanes: chlorine atomc-atalysed destruction of ozone	M. Molina	1974	Nature	3636
Photochemical war on the atmospher	J. Hampson	1974	Nature	39
Stratospheric Ozone Destruction by Man-Made Chlorofluoromethanes	R. Cicerone	1974	Nature	280
Atmospheric halocarbons and stratospheric ozone	J. Chesick	1975	Nature	147
Possible ozone depletions following nuclear explosions	R. Whitten	1975	Nature	27
Natural halocarbons in air and sea	F. Rowland	1975	Nature	308
Chlorofluorocarbon sources of environmental contamination	P. Howard	1975	Nature	15
Alternative refrigerants	W. Megaw	1976	Nature	9
Stratospheric ozone as viewed from the Chappuis band	R. Angione	1976	Nature	21
Alternative refrigerants	R. Ward	1976	Nature	21
Atmospheric temperature calculated for ozone depletions	Beck	1976	Nature	4
Has man increased stratospheric ozone?	H. Ellsaesser	1977	Nature	4
Stratospheric CH_4, HCl and ClO and the chlorine–ozone cycle	M. Ackerman	1977	Nature	11
Will Fertilizers Harm Ozone as Much as SST's?	D. Shapley	1977	Nature	6
A simple calculation of ozone depletion by chlorofluoromethanes using a two-dimensional model	J. Pyle	1978	Nature	9
Ozone increase from Concorde operations?	P. Fabian	1978	Nature	5
Effect of the reaction $HO_2 + O_3 \rightarrow OH + 2O_2$ on stratospheric ozone	R. Whitten	1978	Nature	13
Recent developments in atmospheric chemistry	B. Thrush	1978	Nature	6
SSTs, nitrogen fertilizer and stratospheric ozone	R. Turco	1978	Nature	27
Tropospheric ozone and climate	J. Fishman	1979	Nature	161
The ecological significance of solar UV radiation on aquatic organisms	J. Calkins	1980	Nature	202
Possible existence and chemistry of $ClO \cdot O_2$ in the stratosphere	S. Prasad	1980	Nature	20
Possible ozone reductions and UV changes at the Earth's surface	J. Pyle	1980	Nature	21
Coupled effects of atmospheric N_2O and O_3 on the Earth's climate	Wie-Chyung	1980	Nature	99
A modified diabatic circulation model for stratospheric tracer transport	J. Pyle	1980	Nature	23
Two-dimensional model calculations of stratospheric HCl and ClO	C. Miller	1980	Nature	4
Possible ozone reductions and UV changes at the Earth's surface	J. Pyle	1980	Nature	21
Nitrogen fertiliser and stratospheric ozone: latitudinal effects	R. Whitten	1981	Nature	5

Biologically damaging radiation amplified by ozone depletions	S. Gerstl	1981	Nature	20
Halocarbons in the stratosphere	P. Fabian	1981	Nature	59
On the validation of one-dimensional CFC–ozone depletion models	R. Derwent	1981	Nature	10
Two-dimensional modelling of potential ozone perturbation by chlorofluorocarbons	J. Steed	1982	Nature	5
A 2-D model calculation of atmospheric lifetimes for N2O, CFC-11 and CFC-12	M. Ko	1982	Nature	24
Atmospheric chemistry: Ups and downs in ozone prediction	H. Schiff	1982	Nature	9
New link between ozone and cancer	T. Maugh	1982	Nature	909
Atmospheric chemistry: Ozone fears revisited	H. Schiff	1984	Nature	2
Reductions in ozone at high concentrations of stratospheric halogens	M. Prather	1984	Nature	133
Ozone depletion: Europe takes a cheerful view	A. Lubinska	1985	Nature	6
Large losses of total ozone in Antarctica reveal seasonal ClOx/NOx interaction	J. Farman	1985	Nature	2945
On the depletion of Antarctic ozone	S. Solomon	1986	Nature	1104
Are Antarctic ozone variations a manifestation of dynamics or chemistry?	K. Tung	1986	Nature	113
Deaths foretold	T. Beardsley	1986	Nature	2
Causes and effects of a hole	J. Margitan	1987	Nature	5
Balloon-borne observations of the development and vertical structure of the Antarctic ozone hole in 1986	D. Hofmann	1987	Nature	136
Europe agrees to act for protection of the ozone layer	K. Johnston	1987	Nature	3
West Germany strides towards CFC elimination by 2000	S. Dickman	1987	Nature	8
Agreement nears on protection of the Earth's ozone layer	K. Johnston	1987	Nature	373
High concentrations of chlorine monoxide at low altitudes in the Antarctic spring stratosphere: diurnal variation	R. de Zafra	1987	Nature	120
Expedition faces Antarctic ozone hole mysteries	A. Anderson	1987	Nature	2
Antarctic chemistry to blame	J. Pyle	1987	Nature	8
The great ozone controversy	J. Maddox	1987	Nature	7
Ozone hole deeper than ever	D. Lindley	1987	Nature	5
An important uncertainty in coupled chlorine–carbon dioxide studies of atmospheric ozone modification	R. Eckman	1987	Nature	17
Future emission scenarios for chemicals that may deplete stratospheric ozone	J. Hammitt	1987	Nature	60
Depletion of ozone layer drives competitors to cooperate	A. Anderson	1988	Nature	5
Global ozone trends reassessed	C. Rodgers	1988	Nature	9
CFCs cause part of global ozone decline	D. Lindley	1988	Nature	16
Response of a general circulation model to a prescribed Antarctic ozone hole	J. Kiehl	1988	Nature	84
The stability and photochemistry of dimers of the ClO radical and implications for Antarctic ozone depletion	R. Cox	1988	Nature	182
Causes of ozone depletion	B. Thrush	1988	Nature	17
Ozone destruction and photochemical reactions at polar sunrise in the lower Arctic atmosphere	L. Barrie	1988	Nature	892
Formation of the Antarctic ozone hole by the ClO dimer mechanism	J. Barret	1988	Nature	63
Direct ozone depletion in springtime Antarctic lower stratospheric clouds	D. Hofmann	1989	Nature	25

Scientific Contributions on Arctic Haze

Title	Author	Year	Journal	Citations
An Evolving History of Arctic Aerosols	Garrett, T.	2008	Science	20
Arctic Air Pollution	Law, K.	2007	Science	208
A case study of the radiative effects of Arctic aerosols in March 2000	Treffeisen, R.	2005	Atmospheric Environment	25
European atmospheric emissions of selected persistent organic pollutants, 1970-1995	Pacyna, J.	2003	Atmospheric Environment	97
On radiative effects of black carbon and sulphate aerosols	Kirkevaag, L.	1999	Atmospheric Environment	59
Arctic aerosol factor models: validation by marginally detected elements	Heidman, N.	1994	Atmospheric Environment	3
Arctic green house effect	Blanchet, J.	1994	Atmospheric Environment	
The Dye 3 gas and aerosol sampling program (DGASP): An overview	Jaffrezo, J.	1993	Atmospheric Environment	34
A cautionary note on the use of air trajectories in interpreting atmospheric chemistry measurements	Kahl, J.	1993	Atmospheric Environment	87
The snows of interior Alaska	Shaw, G.	1993	Atmospheric Environment	13
Contamination of Arctic air at three sites during a haze event in late winter 1986	Djupström, M.	1993	Atmospheric Environment	24
Trajectory analysis of source regions influencing the south Greenland ice sheet during the Dye 3 Gas and Aerosol Sampling Program	Davidson, C.	1993	Atmospheric Environment	46
Black carbon (soot) aerosol in the lower stratosphere and upper troposphere	Pusechel, R. F.	1992	Science	89
Aerosol characteristics of Arctic haze sampled during AGASP-II	Parungo, F.	1990	Atmospheric Environment	23
Toward estimation of climatic effects due to Arctic aerosols	Blanchet, J.	1989	Geophysical research letters	56
A major haze event near Point Barrow, Alaska: Analysis of probable source regions and transport pathways	Bridgman, H.	1989	Nature	37
Aircraft measurements of air pollution in the Norwegian Arctic	Ottar, Brynjulf	1986	Atmospheric Environment	33
Arctic air pollution: an overview of current knowledge	Barrie, Leonard A.	1986	Atmospheric Environment	583
Observations of Arctic haze during polar flights from Alaska to Norway	Raatz, W.	1985	Atmospheric Environment	21
Aerosol measurements in central Alaska, 1982-1984	Shaw, G.	1985	Atmospheric Environment	28
Characterization of aircraft-collected particles present in the Arctic aerosol; Alaskan Arctic, spring 1983	Sheridan, P.	1985	Atmospheric Environment	33
Particulate sulfur and chlorine in Arctic aerosols, spring 1983	Winchester, J.	1985	Atmospheric Environment	15
Soot in the Arctic snowpack: A cause for perturbations in radiative transfer	Clarke, A.	1985	Atmospheric Environment	269
Calculated radiative effects of Arctic haze during a pollution episode in spring 1983 based on ground-based and airborne measurements	Wendling, R.	1985	Atmospheric Environment	29
Five years of air chemistry observations in the Canadian Arctic	Barrie, L.	1985	Atmospheric Environment	194
Transport and chemical composition of the summer aerosol in the Norwegian Arctic	Pacyna, J.	1985	Atmospheric Environment	68
Estimates of springtime soot and sulfur fluxes entering the Arctic troposphere: Implications to source regions	Rosen, H.	1985	Geophysical research letters	16
Size-differentiated composition of the Arctic aerosol at Ny-{\AA}lesund, Spitsbergen	Pacyna, J.	1984	Nature	41
Airborne observations of Arctic aerosols. I: Characteristics of Arctic haze	Radke, L.	1984	Science	74
Arctic haze and the Arctic gas and aerosol sampling program (AGASP)	Schnell, R.	1984	Science	107
Vertical and horizontal characteristics of Arctic haze during AGASP: Alaskan Arctic	Schnell, R.	1984	Science	54
Arctic aerosols: Model estimates of interactive influences upon the surface-atmosphere clearsky radiation budget	Cess, Robert	1983	Nature	57
Soot Carbon and Excess Fine Potassium: Long-Range Transport of Combustion-Derived Aerosols	Meinrat O. Andreae	1983	Atmospheric Environment	486
Noril`sk only a minor contributor to Arctic Haze	Kenneth Rahn	1983	Atmospheric Environment	17
Combustion-generated carbon particles in the Arctic atmosphere	H. Rosen	1983	Atmospheric Environment	16
Altitudinal and temporal variation of hydrocarbons and other gaseous tracers of Arctic haze	Rasmussen, R.	1983	Atmospheric Environment	52
Radiative properties of the Arctic aerosol	Patterson, EM	1982	Atmospheric Environment	39
Parametric study of the effects of Arctic soot on solar radiation	Porch, William	1982	Atmospheric Environment	51
Evidence for a central Eurasian source area of Arctic Haze in Alaska		1982	Geophysical research letters	64
Soot in the Arctic	Rosen, H	1981	Atmospheric Environment	163
The influence of mid-latitudinal pollution sources on haze in the Canadian Arctic	Barrie, Leonard A.	1981	Atmospheric Environment	206
Long-range atmospheric transport of cloudactive aerosol to Iceland	Borys, Randolph	1981	Geophysical research letters	14
Speculations on the movement of polluted air to the Arctic	Carlson, Toby	1981	Nature	65
The transfer of airborne pollutants to the Arctic region	Ottar, Brynjulf	1981	Atmospheric Environment	108
Relative importances of North America and Eurasia as sources of Arctic aerosol	Rahn, Keneth	1981	Geophysical research letters	184

The Mn/V ratio as a tracer of large-scale sources of pollution aerosol for the Arctic	Rahn, Keneth	1981	Geophysical research letters	127
Pollution of the Arctic Atmosphere Confirmed	Richard A Kerr	1981	Atmospheric Environment	20
Focus on Polar Research	A. L. Washburn	1980	Nature	8
Global Pollution: Is the Arctic Haze Actually Industrial Smog?	Richard A Kerr	1979	Nature	31
The Asian Source of Arctic Haze bands	Kenneth Rahn	1977	Science	154
Particulate sulfur and chlorine in Arctic aerosols, spring 1983	J. Winchester	1985	Atmospheric Environment	15

Scientific Contributions on Deforestation

Titel	Author	Year	Journal	Citations
Possible climatic impact of tropical deforestation	P. Potter	1975	Nature	85
Atmospheric carbon dioxide and forest clearance	P. Moore	1977	Nature	77
Anthropogenic Albedo Changes and the Earh's Climate	Carl Sagan	1979	Science	215
Detecting CC due to increasing CO2	Madden	1980	Science	
Global Deforestation: Contribution to Atmmospheric Carbon Dioxide	Woodwell	1983	Science	272
Greenhouse Warming Still Coming	R. Kerr	1986	Science	27
Carbon cycle: Photosynthesis seen from above	R. Warrick	1986	Nature	3
Tropical Forests ad the Global Carbon Cycle	R. Detwiler	1988	Science	523
Simulation of the regional climatic impact of Amazon deforestation	J. Lean	1989	Nature	401
Amazon Deforestation and Climate Change	Shukla, J.	1990	Science	891
Effects of boreal forest vegetation on global climate	G. Bonan	1992	Nature	757
Feedbacks between climate and boreal forests during the Holocene epoch	J. Foley	1994	Nature	452
Carbon Dioxide Uptake by an Undisturbed Tropical Rain Forest in Southwest Amazonia, 1992 to 1993	J. Grace	1995	Science	497
Black Carbon and the Carbon Cycle	T. Kuhlbusch	1998	Science	234
Changes in the Carbon Balance of Tropical Forests: Evidence from Long-Term Plots	O. Phillips	1998	Science	770
The value of the world's ecosystem services and natural capital	Costanza, R.	1998	Nature	487
Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon	R. Houghton	2000	Nature	703
Storing Carbon on Land	R.J. Scholes	2001	Science	122
Carbon sink for a century	J. Chambrs	2001	Nature	121
Royal Society disputes value of carbon sinks	D. Adam	2001	Nature	9
Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems	D. Schimmel	2001	Nature	1105
Determination of Deforestation Rates of the World's Humid Tropical Forests	F. Achard	2002	Science	1605
Carbon in Amazon Forests: Unexpected Seasonal Fluxes and Disturbance-Induced Losses	S. Saleska	2003	Science	517
Fire science for rainforests	M. Cochrane	2003	Nature	580
The Importance of Land-Cover Change in Simulating Future Climates	J. Feddema	2005	Science	565

Brazilian Amazon being cut down twice as fast	M. Hopkin	2005	Nature	15
Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO_2	B. Stephens	2006	Science	501
Reassessing Carbon Sinks	D. Baker	2007	Science	39
Total destruction of forests predicted to cool Earth	J. Giles	2007	Nature	
Forests and Climate Change: Forcings, Feedbacks	G. Bonan	2008	Science	1354
Old-growth forests as global carbon sinks	S. Luyssaert	2008	Nature	712
Storing carbon in forests	M. Obersteiner	2009	Nature	1
Dying trees may exacerbate climate change	H. Hoag	2009	Nature	
Deforestation emissions on the rise	J. Tellefson	2009	Nature	2
Climate: Counting carbon in the Amazon	J. Tellefson	2009	Nature	22
Boreal forests' carbon stores need better management	S. Pimm	2009	Nature	8
Model predicts future deforestation	A. Nayar	2009	Nature	2
Amazon is best site for forest carbon investments	A. Nayar	2009	Nature	
The Incidence of Fire in Amazonian Forests with Implications for REDD	L. Aragao	2010	Science	124
Saving forests, cultures and carbon dioxide	A. Nayar	2010	Nature	2
A Large and Persistent Carbon Sink in the World's Forests	Y. Pan	2011	Science	953
Cash alone will not slow forest carbon emissions	A. White	2011	Nature	8
Carbon from Tropical Deforestation	D. Zarin	2012	Science	18
Uncertainty: Climate models at their limit?	M. Maslin	2012	Nature	65
Earth science: The balance of the carbon budget	I. Levin	2012	Nature	6
Carbon sequestration: Managing forests in uncertain times	V. Bellassen	2014	Nature	9
Deforestation: Carving up the Amazon	B. Fraser	2014	Nature	2
Baseline Map of Carbon Emissions from Deforestation in Tropical Regions	N. Harris	2912	Science	148