Formalizing knowledge on international environmental regimes for integrated assessment modeling

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Abstract
International environmental regimes are considered key factors in dealing with global environmental problems. It is important to understand if and how these regimes are effective in solving or improving global environmental problems. In this paper we present a multidisciplinary approach to formalize knowledge on the effectiveness of environmental regimes. We constructed a conceptual framework to enhance systematic analysis of conditions that influence regime effectiveness and implemented this into a computer model using fuzzy logic reasoning. We applied the model in a preliminary analysis of two environmental regimes, the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change. The model can be used to analyze past and future attempts to develop and implement environmental regimes, highlighting the determinants which contribute to success or failure. Results from these analyses can be used to improve scenario storylines in integrated assessment modeling. Although this paper shows that formalizing knowledge on environmental regime theory is not a trivial endeavor, it facilitates and improves the cooperation between scientists from regime theory and integrated assessment.

Keywords**:** regime; governance; institutions; integrated assessment; fuzzy logic

1. Introduction

The current generation of environmental problems has attributes which distinguish them from earlier environmental problems, and which need to be taken into account when thinking about policy measures. They concern 'global public goods', are transboundary and they are characterised by high uncertainty, multiple interests and complexity, requiring transdisciplinary approaches to deal with them. In order to address these environmental problems most effectively and efficiently, society has started to pursue global solutions. This has resulted in a series of systems of rights and obligations and related decision-making procedures in international environmental policy, also known as international environmental regimes [Biermann 2007]. International environmental regimes are considered key factors in dealing with global environmental problems [Biermann 2007]. It is therefore important to understand if and how regimes are effective in tackling these problems.

The creation and performance of international regimes to solve international environmental problems is studied by the field of international relations and more specifically by environmental regime theory. Traditionally, regime theorists have measured the effectiveness of regimes in qualitative terms, especially through the structured, focused comparison of different case studies. However, to be able to draw lessons for policy making this approach suffers from problems of comparability and generalisability [Biermann et al., 2007]. Integrated assessment is a methodology to analyze global environmental problems by combining knowledge from the social, environmental and economic domains (People - Planet - Profit) relying strongly on quantification and computer simulation, while also recognizing the importance of including more qualitative forms of knowledge [Rotmans and Dowlatabadi, 1997]. For effectively dealing with problems such as climate change and biodiversity loss in a sustainable manner scientists in the field of integrated assessment acknowledge that it is important to include knowledge on environmental regimes in their analyses [Netherlands Environmental Assessment Agency, 2008]. But as attempts to quantify or model political processes have not yet been successful, knowledge on environmental regimes is often of minor importance in integrated assessments of sustainable development [Biermann 2007]. In the multi-disciplinary project Modeling Governance and Institutions for Global Sustainability (ModelGIGS) the challenge of bringing both worlds together this is taken up.

In this paper we present a cutting-edge approach to formalize knowledge on the effectiveness of environmental regimes. Eventual aim of our research is to include this knowledge in integrated assessments of global environmental problems. But as we don't think that at this stage this type of knowledge can be fully integrated in integrated assessment (IA) models, this is envisioned to be an extension of current IA models. In practice, this means that the analysis of environmental regimes will be used to strengthen scenario storylines for IA simulation models, e.g. by analysing policy options which explicitly account for potential success and fail-factors in establishing effective environmental regimes.

In our research we constructed a conceptual framework to enhance the systematic analysis of conditions that influence regime effectiveness. We expect added value of this framework as a tool to perform quick assessments of regimes and the options to improve their effectiveness. Therefore we implemented the framework in a computer model using fuzzy logic methodology [Zadeh 1965], a simple and straightforward way of linguistic reasoning. Our paper is divided into 5 sections. Section 2 describes the formalization of knowledge from environmental regime theory and the construction of the conceptual framework. Section 3 describes our method to model the framework using fuzzy logic. In Section 4 we apply our model in an illustrative, tentative analysis of two environmental regimes, the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC) In section 5 we discuss our main findings on the usefulness and prospects of our framework and model. Throughout the paper we will reflect on methodological challenges we encountered in our research.

2. Formalizing knowledge and building a conceptual framework

2.1. Regime effectiveness

When measuring the performance of international regimes, scholars by and large focus on the behavioral change of key actors (i.e. states) and not on environmental improvements [Easton 1965; Underdal 2002]. Even though some scholars recognize the need to look at environmental improvement, measurement is difficult because it is almost impossible to disentangle regime impacts from influences that are independent from the regime. In this paper we use the terms 'likelihood of regime formation' and the 'likelihood of regime implementation' as representatives for the performance of international environmental regimes. Regime formation and implementation are two distinct phases in the development of a regime. While the former includes the negotiations among states, the latter includes the process of putting the regime's stipulations into practice. We assume that if both stages are completed successfully, a regime will have a good performance. We also assume that good regime performance will lead to environmental improvement.

In an assessment of literature on environmental regime theory [Frantzi 2010) we identified general findings on regime performance and translated this knowledge into a set of approximately 50 clear rules on the likelihood of regime formation and implementation. As an example the rules on the likelihood of regime formation can be found in appendix B.

2.2. Conceptual framework

From the rules we identified the determinants of 'likelihood of regime formation' and 'likelihood of regime implementation'. The next step was to relate the determinants, i.e. input variables, and the two phases of regime performance, i.e. output variables, together in a conceptual model (figure 1).

We have distinguished the input variables in 'context' and 'design'variables. There are three categories of 'context' variables: 'problem structure', which refers to attributes of the environmental problem , '(state) actors', which refers to the (state)actors who take part in negotiations on the regime , and 'regime environment' which concerns the background against which regime formation or implementation takes place. The 'design' variables refer to the influences that policy makers can exert to establish regime formation or implementation, and they in fact can mitigate or enhance the impact that the 'context' variables have on the likelihood of regime formation or implementation. For example the context variable 'asymmetry' describes the asymmetry in actors' interests, which may negatively affect the likelihood of regime formation (figure 1). Designing policy measures such that 'differentiated responsibilities' are allowed for the different (state)actors, can help to mitigate the negative impacts of the asymmetry in their interests, thus enhancing likelihood of regime formation.

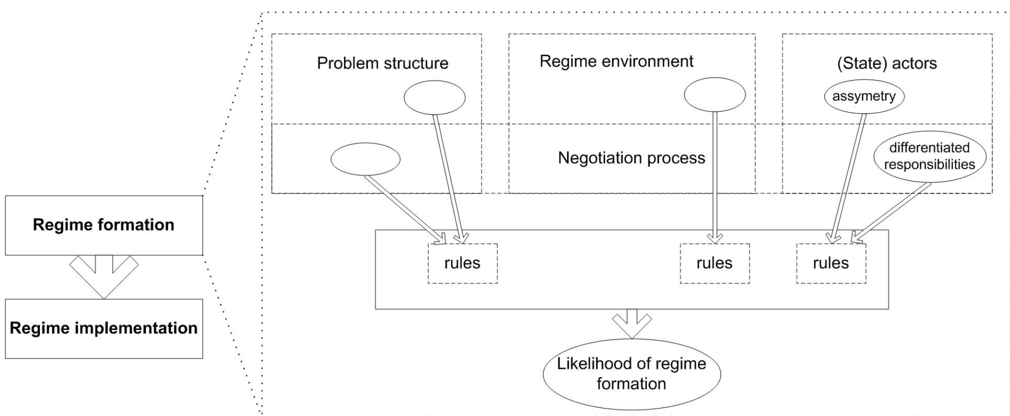

Figure 1 Conceptual framework for the analysis of the likelihood of regime formation. The framework for regime implementation is similar, except for 'negotiation process' which is replaced by 'regime design'. Not all variables drawn from the rules are important in both stages.

The conceptual framework serves as a simple representation of determinants of regime performance. The categorization of the identified (input) variables into 'problem structure', 'regime environment' and '(state) actors' provides some structure and overview. In regime theory, however, these categories are not recognized as separate entities with an associated aggregate indicator referring to their importance for regime performance, nor for a more hierarchical construction of the framework. Besides, although regime formation and implementation are processes in time, we could not find clear information in literature on the temporal dynamics involved. Therefore time is not explicitly considered in our framework and all input variables are supposed to effect the output variable at the same time. We also expect that there are interactions between the input variables, but again, as we did not find clear information in literature, we so far treated all input variables as independent entities. Including linkages between different variables will then need to be based on expert judgment.

3. Modeling the framework

We modeled the conceptual framework to enable future integration of knowledge on the performance of international environmental regimes in integrated assessment analyses.
We had a clear set of rules on the likelihood of regime formation and implementation. However, the corresponding determinants were difficult to define and data were ambiguous, uncertain, lacking or only available as expert knowledge. We therefore chose to model our conceptual framework using the fuzzy logic methodology [Zadeh 1965]. The core of the fuzzy logic methodology is the rule base. We could easily transform our rules on regime performance into a set of fuzzy rules to perform fuzzy logic reasoning. Another basic concept of fuzzy logic is that it uses linguistic variables, thus performing computation with words rather than numbers. It therefore provided a systematic and transparent way of dealing with the determinants of regime performance, for which a straightforward quantification was impossible. Furthermore, fuzzy logic is able to use all types of (quantitative and qualitative) information and yields concrete answers which could eventually be related to quantitative approaches in integrated assessment analyses.

In this section we explain our steps to assess regime performance in a 'fuzzy logic' manner. Data on the input variables may be based on indicators or on expert-judgment. We aim for basing the analysis on the more objective indicator-based approach, however due to lack of time in this paper we use expert-judgement for our case study analyses. For the implementation of our model we have used the freely available fuzzy toolbox of Babuška [1995], which runs under Matlab.

3.1. Quantification and fuzzification of input variables

First step is to quantify the input variables and translate them into linguistic categories, a process called fuzzification. Some input variables can only take a binary value, like the presence of 'differentiated responsibilities' which may either be true or false. For other input variables we will select quantifiable indicators as representatives, based on relevance and data availability. For example the variable 'asymmetry' (of state actors interests)' which may be represented by an indicator like Gross Domestic Product of the countries involved, can take real numerical values. We will normalise the numerical values on a uniform scale from 0 to 10, to have a similar basis for all real-valued input variables. Variables with binary values are straightforwardly assigned to two linguistic categories YES – NO (or equivalently, present/absent, true/false). For input variables with numerical values we employ three linguistic categories LOW - MEDIUM – HIGH to expressing them linguistically. The actual translation of these numerical input values into these linguistic categories (i.e. the fuzzification) is established by means of membership functions for these categories (see figure 2 for an example). These membership functions assign to each value x of the input variable a membership grade between 0 and 1 which expresses to what extent this specific input-variable/value belongs to these categories (i.e. is LOW, MEDIUM, HIGH). For example, if the variable 'assymetry' has value 6, it will be categorized as mainly medium (membership grade

0.8) and a little bit high (membership grade 0.2). For the output variables we employ 5 linguistic categories, viz. VERY LOW - LOW- NEUTRAL - HIGH - VERY HIGH, to obtain more differentiation in our statements on the likelihood of regime formation or implementation.

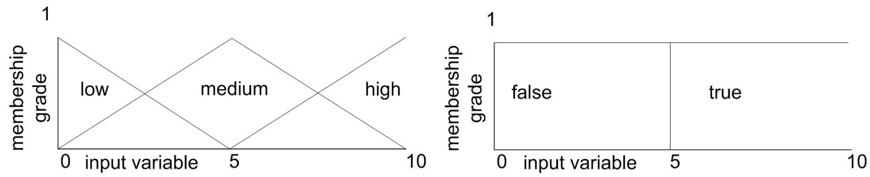

Figure 2 Membership functions to translate in and output variables into linguistic categories.

3.2. Fuzzy inference model

The heart of the fuzzy logic method is the fuzzy rule base, which in fact reflects our knowledge on the system that we analyse. The fuzzy rules are described in terms of IF-THEN statements, relating input variables with the output variable. The fuzzy rule base for our conceptual framework has been obtained by first translating the rules in appendix B, which reflect the knowledge on regime performance as listed in [Frantzi, 2010], into IF-THEN statements. For example the rule *"Great asymmetry of state actors' interests decreases likelihood of regime formation."* would be translated as

1. IF asymmetry is high THEN likelihood of regime formation is very low

This rule involves a single input variable (asymmetry), but there are also rules which describe the combined effect of input variables, as for instance *"If a problem is marked with great asymmetry of state actors' interests, differentiation of responsibilities increases likelihood of regime formation"*, in which a context variable (asymmetry) and a design variable (differentiation of rules) is involved. Notice that this rule is in fact a further specification of Rule 1 above, which illustrates the mitigating effect of a specific policy measure (differentiation of rules) on the negative impact of asymmetry on the likelihood of regime formation. To reflect this mitigating effect and to prevent unnecessary rule-conflict in our fuzzy rule base we have therefore replaced Rule 1 by the following set of rules:

1. IF asymmetry is high AND differentiation is true THEN likelihood of regime formation is low
2. IF asymmetry is high AND differentiation is false THEN likelihood of regime formation is very low

In this way we have constructed our fuzzy rule base directly from the rules in appendix B. Since the rules in appendix B do not cover all possible linguistic values of the input variables (e.g. there are no rules on likelihood of regime formation for situations where asymmetry is low or medium), we have artificially extended the fuzzy rule base by adding rules which conclude on neutral likelihood of regime formation in these situations, e.g.:

3. IF asymmetry is medium THEN likelihood of regime formation is neutral
4. IF asymmetry is low THEN likelihood of regime formation is neutral

With the fuzzy rule base thus constructed we can for a given set of input variables evaluate the likelihood of regime formation and implementation. This activity is called *fuzzy inference* and is performed by means of Mamdani's min-max inference [Jang, 1997]. Each rule is activated by first determining the *degree of fulfillment* of the rule's antecedent, which is equal to the membership-grade of the condition in the IF-part. The inferred implication of the rule's antecedent is established by redefining the membershipfunction of the rule's conclusion, i.e. the

THEN-part. An aggregation process is performed next to infer the overall conclusion of all activated rules taken together.

3.3. Defuzzification: calculation of likelihood

The fuzzy inference of the previous step has resulted in an overall fuzzy conclusion on the likelihood of regime formation or implementation, represented in terms of an encompassing membershipfunction obtained in the aggregation process. The final step in our fuzzy logic framework involves the back-translation of this fuzzy information into a crisp value for the likelihood. For this defuzzification we use the center of gravity method, which determines at what output value the area under the membershipfunction is divided in two equally sized-subareas.

This final output value of our model gives an indication of the likelihood that a regime will be formed or implemented in a given situation. A low likelihood does not necessarily mean that regime formation or implementation do not take place, but rather indicates that formation or implementation is very difficult in the given circumstances. In addition to this overall output value, we have also calculated the results from the rules on the three categories of context variables to determine the contribution of each category to the final output. These results however cannot be seen as intermediate or separate results, but should be used to gain insight in the principal factors influencing the end result.

4. Applying the framework on the international biodiversity and climate regime

As an illustrative example of how our model may be used, we made a tentative calculation of the likelihood of formation of two existing regimes: the Convention on Biodiversity (CBD) and United Nations Framework Convention on Climate Change (UNFCCC) (figure 3). Data were derived by making an educated guess based on expert assessment of the official documents of the regimes (appendix A).

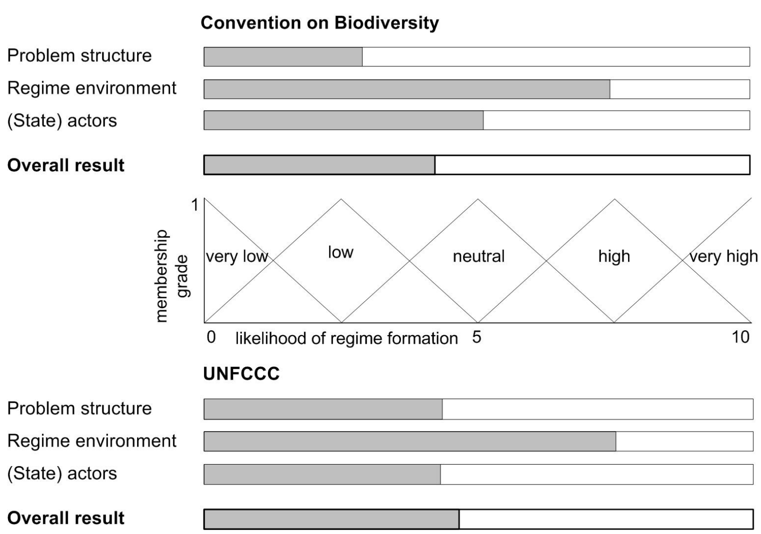

Figure 3: Tentative calculation of likelihood of regime formation for the Convention on Biodiversity and UNFCCC. Figure shows both overall likelihood results and the contribution of the three categories of context variables.

Looking at the overall results, formation of the biodiversity regime appeared slightly harder than formation of the climate regime. The contribution of the three categories of context variables provides insight in the possible causes for this difference. The characteristics of the biodiversity problem, i.e. the problem structure, were less favorable for regime formation than the characteristics of climate change. Biodiversity is a cumulative problem, which means that it has local causes, but global effects, which decreases the likelihood of regime formation. Whereas climate change is a systemic problem, which means that both causes and effects are global increasing the likelihood of regime formation. Also, society considered the biodiversity problem less urgent and salient, i.e. put it lower on the political agenda, than climate change. On the other hand, factors concerning the (state) actors were more favorable in the biodiversity regime. This is mainly caused by the fact that there was a big coalition of countries in favor of the biodiversity regime, whereas the climate change regime was confronted with a big coalition against opposing it. Both regimes had favorable regime environment because of their scientific advisory bodies, which helped the negotiations with providing necessary scientific information.

The likelihood of regime formation in both regimes could be enhanced by trying to influence the variables that are diagnosed above. Negotiations for both regimes could for example be linked by countries with other issues to enable trade-offs in the negotiation process. Furthermore, negotiations concerning the biodiversity regime may benefit from differentiated responsibilities for the different (state) actors which could mitigate the high asymmetry between the actors' interests. This analysis of design options to enhance regime formation and implementation will be developed further when we have performed a validation of our conceptual model on various regimes, preferably indicator-based.

5. Discussion an conclusions

The model can be used to analyse the successful or failed attempts to develop regimes in the past, highlighting which determinants contributed to this success or failure. Moreover it can be used to assess future situations where there is no regime formed yet, and to suggest promising options for successful regime formation. Preferably the analysis of regime formation should be linked further to regime implementation, as we would be most interested in those factors from the regime formation phase that are also relevant in the regime implementation phase (as de facto we see a situation of regime formation having taken place for most international environmental problems).

The interpretation of the quantitative output of the model is difficult, as there is neither a universally accepted definition nor metric of the likelihood of regime formation and implementation. However, the quantitative model results enable meaningful comparisons between regimes and policy measures. The contributions of the three different categories to the overall result may help to understand the causes and structures of regime effectiveness. The analysis of the two regimes in the previous section should be considered as illustrative for the type of outcomes we are working towards.

The model enhances the transparency of knowledge on environmental regimes since it explicitly specifies important determinant factors and their potential effects on regime formation and implementation, in terms of the underlying rule base in the fuzzy inference model. In this way it is expected to offer researchers in integrated assessment useful insights in environmental regime theory, whereas it also may challenge regime theorists to structure and increase their knowledge further. In constructing our model from the underlying knowledge base we were namely confronted with questions regarding appropriate chronology, hierarchy and interaction of the identified factors which influence regime performance. Discussing our model and its application with regime theorist could trigger them to address these questions, leading to a further extension and improvement of the knowledge base and our model.

A serious limitation of our approach is the subjectivity in the choice and scoring of indicators and in the definition of membership functions. Both data on indicators and parameters of the membership functions usually cannot be derived entirely from the literature and must be based at least partly on the expert knowledge and judgment of the model developer. Currently we have suggested rather indicative and pragmatic choices on these issues, but in the future more explicit expert-elicitation should be invoked to obtain a better underpinning [cf. Cornelissen et al., 2004]

At this stage it is not yet possible to link our model to an integrated assessment model as the scope and variables differ too much. But results from analysis with the model can be used to improve scenario storylines in integrated assessment modeling. The storylines could account for the existence and performance of relevant future environmental regimes as projected by the modeland the factors that need to be in place for good regime performance can be identified and included as well(currently that is not happening or even contradicting assumptions may be included). We believe, however, that the integration of the knowledge on environmental regimes in integrated assessment modeling is in its early days and needs further attention.

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Appendix A Input variable values (based on expert judgement) for calculation of likelihood of regime formation for the Convention on Biodiversity and UNFCCC

Variable	Convention on Biodiversity	UNFCCC
	Normalized value	**Normalized value**
Problem structure		
Urgency	5	8
Scientific uncertainty	5	5
Regulation costs	8	8
Saliency	5	8
Systemic problem	0	10
Collaboration problem	10	10
Initial informal agreement	0	0
Transaction costs	8	8
Initial framework treaty*	10	10
Positive sidepayments *	10	10
Positive issue linkages *	0	0
Negotiation costs*	2	8
Regime environment		
Preceding agreement	0	0
Scientific advisory bodies	10	10
(State) actors		
Assymetry in actors' interests	8	8
Powerful pushers	10	0
Powerful laggards	0	10
Support of important states	0	0
Cumulative cleavages	10	0
Number of actors	8	8
Homogeneous actors	0	0
Differentiated rules*	0	10
Positive or negative incentives*	10	10

* Variables in the category 'negotiation process'; these can be deliberately influenced by the actors.

Appendix B Rules on the likelihood of regime formation

1. The existence of a preceding agreement or policy dealing with the same or a similar problem enhances the likelihood of regime formation.
2. The higher the negotiation costs, the less likely is regime formation.
3. The higher the regulation costs, the less likely is regime formation.
4. In case of high transaction costs and scientific uncertainty, initial framework agreements followed by more precise agreements increase likelihood of regime formation.
5. High saliency of the problem, increases likelihood of regime formation.
6. If the environmental problem is urgent, an initial informal agreement increases likelihood of regime formation.
7. If the environmental problem is considered urgent by the majority of actors, then regime formation is more likely.
8. Systemic problems increase the likelihood of regime formation.
9. Cumulative problems decrease the likelihood of regime formation.
10. Scientific uncertainty decreases the likelihood of regime formation.
11. Consensual scientific information by scientific advisory bodies increases the likelihood of regime formation.
12. In case of cumulative cleavages, regime formation is less likely.
13. In case of cumulative cleavages, regime formation is more likely if there are positive or negative incentives.
14. Great asymmetry of state actors' interests decreases likelihood of regime formation.
15. If a problem is marked with great asymmetry of state actors' interests, differentiation of responsibilities increases likelihood of regime formation.
16. If the coalition of 'pushers' is more powerful than the rest, regime formation is more likely.
17. If the coalition of 'laggards' within a regime is more powerful than the rest, regime formation is less likely.
18. If powerful states within the issue area are part of a regime, then regime formation is more likely.
19. The fewer actors are needed to regulate an environmentally harmful activity, the more likely is regime formation.
20. If the actors needed to regulate a harmful activity are homogeneous, then regime formation is more likely.
21. In case of a collaboration problem, regime formation is less likely.
22. In case of a collaboration problem, regime formation is more likely if there are positive side-payments.
23. In case of a collaboration problem, regime formation is more likely if there are positive issue-linkages.