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# Policy Emergence

An agent-based approach

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TU Delft

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by

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# Preface

This thesis report is written as part of the Master Program in Engineering and Policy Analysis at the Faculty of Technology Policy and Management. It marks the final step in completing this study at the TU Delft.

I chose this subject during my first year at the faculty because I thought it would be challenging. The combination of modelling, simulation and political sciences intrigued me and the large scope made this project very attractive to me. Overall, I was not disappointed as the topic was challenges and required a lot of work.

I could not have done this work on my own. I would first like to thank Amit Ashkenazy, my daily supervisor. Our weekly meetings provided me with deep insight into the work I was doing, always providing an example to illustrate one of my issues. I would also like to thank Pieter Bots for his insights that helps me through the entire conceptualisation and which provides appreciated critical feedback. I would like to thank Igor Nikolic for his insights on the simulation side and how to address the amounts of data that I produced. Finally, I would like to thank Paulien Herder for her insights and feedback on my draft report and my approach to the entire topic.

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*R. Klein*
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# Summary

The policy emergence process is a complex process. Since the inception of the field, researchers have gained knowledge about this process and have started devising theories to explain this process. The work presented in this report looks at how a few of these theories can be conceptualised, formalised and simulated. The aim of this work is to answer the following research question: *To what extent can a formal simulation model represent the policy emergence process theories?* Due to time constraints and a limited scope, only four policy making theories are considered: the three streams theory, the feedback theory, the advocacy coalition framework (ACF) and the diffusion theory.

Chapter 2 goes over the literature that is available on the four policy making theories along with the policy entrepreneurship model. The three streams theory is a theory that approaches the policy process as a process with no beginning or no end. It assumes that this process is composed of three steams: policy, problem and politics. Two or more of these streams can meet creating a policy window. When this window is open, the actors will discuss and can achieve an agreement on a policy instrument. The feedback theory is a theory that looks at the policy instruments and assumes that when implemented, they will have can have a feedback effect on the policy process. These feedbacks are categorised in four main families: the meaning of citizenship, the form of governance, the power of groups and the political agenda and definition of problems. The advocacy coalition framework is a framework that assumes that actors are part of a subsystem in which they are grouped into coalitions. Within these coalitions and between these coalitions, actor interaction leads to policy learning which can ultimately lead to policy emergence. The diffusion is a theory that codifies the diffusion of policies between different systems. According to this theory, policy emergence can happen following one of five methods: learning, imitation, normative pressure, competition or coercion. Finally, the policy entrepreneurship is a model that outlines the interactions between the actors in the case of three streams theory where this model is mostly used. It is in opposition to the advocacy coalition model that is used within the advocacy coalition framework.

Chapter 3 presents the conceptualisation that is developed based on the literature review. The approach taken is one where common concepts are combined into a common core that conceptualises a the policy emergence process. Some of those concepts are the belief system that is taken from the ACF, the iterative stages that are assumed to constitute the process, the types of actors and the actions they can perform. The belief system is a tiered belief system composed of issues. For each issue, each actor has an aim and a perception of the world state for that issue. The issues are also related through causal relation which are a way of understanding how the world works from the actor's perspective. The actions that the actors can perform are influence on the aims of the issues, the perception of these issues and the causal relations. There are two types of actors: active (policy entrepreneurs, policy makers and external parties) and the passive actors (constituencies). To this common core are added extensions that represent the different specificities of the policy making theories. For the three streams theory, the additions are the teams that the actors can form temporarily to push certain issues forward and the availability of choice between a policy or a problem. For the ACF, the addition is mainly the coalition concept. Actors are assigned to coalitions depending on their beliefs and these coalitions are used to engage in policy learning. For the feedback theory extension, feedback effects are added to the policy instruments being implemented. And for the diffusion theory, a complementary approach is used on how influence between the actors can occur between different systems. These influences are dependent on the relations between the systems which follow the approach provided in the literature. This conceptualisation was validated through expert interviews. Their feedback had an impact on the concepts used and adjustments were made after the interviews were conducted.

Chapter 4 looks at the formalisation of the conceptualisation. This chapter is used as a bridge between the conceptualisation and the implementation. It helps outlined and fill all the holes that are still present with the conceptualisation before the models can be coded. Structured in the same way was the conceptualisation, it first looks at the common core. The subsystems, agents, belief hierarchy, policy network, affiliation network and the actions are all defined in details. The equations are also provided for how the agents calculate their issue preferences, how they select the agenda and how they select policy instruments. The additional actions that are performed by the external parties are also added. The model cycle that is used for the common core is then given with these four main steps: world simulation, agenda setting, policy formulation and end of tick procedures. The three streams theory formalises the policy instruments and the instrument hierarchy. It also provides the grading scheme necessary to estimate the preferences of the policies. The new actions associated to the policies are presented. Finally, the teams are outlined. This comes with the algorithm and assumptions that are used to define when a team can be created, when it has to disband or when actors can join a team. For the advocacy coalition framework extension, the coalition and the algorithms around these coalitions are defined. The feedback theory defines how the feedback effect must be added by the modeller on the set of policy instruments s/he will define. For the diffusion theory, the super-policy network, the subsystem network are both outlined along with the equations that are needed for coercive relations between two subsystems.

The implementation of the formalisation and the conceptualisation is outlined in Chapter 5. An agent based approach is used to implement the model. This is because of the needs for agents to formulate the different parts of the model. It is also due to the need to simulate the emergence side of the policy emergence process. The approach taken is therefore a cyclic one which is required for any agent based model. The model is initialised, then for each tick the different actors inter-actions are performed along with the simulation of the world model. At the end of each tick, the data from the model is saved. The world model that is used is a forest-fire agent based model. This model is taken from the Project Mesa folders and then modified to add slightly more complexity. For this, a belief hierarchy is created with three layers. A procedure is also created to calculate the states of each of these issues which are to be transmitted to the agents in the model. The model parameters that are to be recorded are outlined. These are mostly parameters related to the agents and the model itself (agenda and policy implemented). Because of size and time constraints, not all possible parameters are recorded and a choice has to be made. The entire model is implemented in Python. This is a new approach to agent based models which are usually implemented in NetLogo. However, Python is found to be more adequate considering

the complexity of the model and the data structure required for the different parameters in the model. The verification process that is used to check the code implemented is mostly reliant on the print function from Python. The entirety of the code was checked to see whether the expected outcome was indeed the actual outcome.

Chapter 6 outlines the steps that were taken to simulate the model that is implemented in the previous chapter. To simulate the model, different categories of endogenous parameters have to be taken into account. These are world model parameters, policy emergence parameters, agents related parameters, policy network parameters, and teams and coalition parameters. Once again, because of the number of a parameters present in the model, only a few were selected to be changed for each experiment. The model warmup is also explained as it plays a crucial role in the partial knowledge of the agents and therefore the likelihood that they perform the appropriate actions. The problem then relates to the goal of having comparable results. To achieve that, it was decided that the policy network must remain the same throughout all experiments. The first set of experiments is the model exploration. Within these experiments, extreme values are used to see whether the model will break or how the model is affected by these values. Then a set of experiments is run as a parameter sweep of the model. These experiments are all run without any external event. The last set of experiments introduces a number of external event to try to see if the effect of the external event is present as expected.

In Chapter 7 the results are presented. The first observation that is made is that there is a flaw with the results of the forest fire model and the implementation of the policy instruments. The main reason behind this flaw is related to the inappropriate approach used to connect the world model and policy emergence model, and to calculate the states of the issues present in the belief hierarchy. However, beyond these issues, the model shows promising results. When considering the expected results from the ACF, policy learning is present in the model. The coalitions are also behaving appropriately according to the literature although issues remain related to the initialisation of the partial knowledge of the agents. The four models (backbone, backbone+, three streams and ACF) do show differing outcomes. These changes can be related to the introduction of the teams concept in the three streams theory and the coalitions concept in the ACF. Some issues arise with the results from the parameter sweep. It is very difficult to see what impact the different parameters have on the model from the results obtained. Following these issues, it is advised by the author to record more parameters in subsequent studies. These are the parameters that define which action is performed, with which impact, by whom and on which agents. Finally, the results from the external event experiments show a consistent outcome with the one expected from the conceptualisation and formalisation.

Chapter 8 concludes this report. It provides an answer to each of the research subquestions that were outlined to structure the report. It then provides a reflection on some of the important points raised by this work. The first one relates to the model complexity which can both considered to be an asset and a liability. It is also argued that it would be very hard to obtain a model with this level of fidelity without this level of complexity. An argument is then made about the simplification and uniformisation of the actor actions which is presented subsequently in the appendices. The overall scientific contribution is then provided with most noticeably the advancing of the field of policy analysis through the use of simulation which is a new approach. The different tasks that can be performed to enhance the work presented are then outlined. These tasks go from the implementation

of the newly slimmer and simpler formalisation to the addition of extensions regarding the emergence of the policy instruments themselves. This report is then concluded by answering the main research question.

# Contents

# 1 Introduction

Policy processes are complex and non-linear (Morçöl, 2013). Over time, researchers have acquired more knowledge about these processes by devising theories that attempt to explain parts of what they believe is in the policy process. The aim of such research is for policy analysts to become better and more effective at what they do.

Multiple theories have been devised to codify, try to explain and try to understand what occurs during these policy processes (Sabatier and Weible, 2014). Any policy process can encompass hundreds of different actors interacting with each other. It can also happen on different time scales. Each policy process is different depending on the political arena considered, may it be the health or the transportation industry. Their policy process will also be different from one country to another varying with the types of institutions and the legislative process. Finally, the policy process deals with the beliefs of the agents present in the political arena. These beliefs can vary widely from one actor to another regarding similar topics (Sabatier and Weible, 2014).

The current approaches looking at policy emergence use mostly a mix of qualitative theories and case studies stemming from these theories. This approach is limited in its scope and so is the understanding that can be gained from it. However, synthesising and simulating such theories might help researchers better understand these policy processes. This approach is used within this thesis.

This thesis presents a conceptualisation of four policy making theories. Following, a formalisation of this conceptualisation is elaborated. It is followed by the implementation and simulation of the devised models. Finally, an initial study of the results is performed. This introductory chapter outlines the basic literature related to the policy emergence in Section 1.1 and the four policy making theories considered in Section 1.2. It then introduces the research approach and the objectives of the work presented in this report in Section 1.3. It is completed by an outline of this report in Section 1.4.

## 1.1. Policy Emergence

Currently, the study of policy emergence is mostly conducted through qualitative studies. These studies focus on specific cases (Ackrill and Kay, 2011; Birkland, 2004; Bloemraad et al., 2008; Cairney, 2009; Dolšak and Sampson, 2012; Hoberg, 1996; Hochschild and Weaver, 2010; Ingold, 2011; Kim, 2003; Mazarr, 2007; Mettler, 2002; Pierce, 2011; Travis and Zahariadis, 2002). For such case study, the researcher adopts a certain lens to analyse what has occurred. These lenses are shaped based on the varying policy making theories. This approach to analyse the process of policy emergence is limited in several aspects.

Using a qualitative approach, it becomes more complicated to analyse and compare the same case studies but in different legislations or with different institutions. Such an approach limits the analysis that can be performed by researchers. Another problem relates to the policy making theories themselves. As these theories are very qualitative, and not fully formalised, the analysis will lack the sort details that could be obtained through a more quantitative study. These are details such as which actors spoke to who and what were the impacts of such discussion on the overall process. The qualitative approach provides a fundamental understanding of the overall events, but lacks the clarity of a quantitative analysis. Finally, and maybe most importantly, the qualitative approach is a static analysis. Using such an analysis, it is impossible to test different scenarios with different events or agents to see whether the outcome could have been impacted by a different set of circumstances. It is also impossible to check whether the proposition of different instruments to the actors present in the system would have led to a different outcome.

It is for these reasons that it is important to attempt to conceptualise and simulate these policy making theories. The resulting model would yield an innovative approach to look at the policy emergence process. It would also allow researchers for additional insight in this process. Additional tests could be performed and tests on changing outcomes could be conducted.

Despite these advantages, it is important to understand that a lot of assumptions will be needed to conceptualise, formalise and operationalise the qualitative policy making theories. These assumptions can help gain a better understanding of the theories while forcing researcher to think about whether such assumptions are correct. These assumptions will however also require to be tested and assessed in rigorous experimental setup which is a time consuming effort. Although this thesis will provide these assumptions, it does not provide a full rigorous experimental testing. Rather, limited testing based on a simple case study is presented due to the time available for the work presented here.

## 1.2. The Policy Making Theories

For the purpose of this thesis, four theories are of paramount interest. They are the three streams theory, the feedback theory, the advocacy coalition framework and the diffusion theory. Several reasons can be used to justify why only these four theories are considered amongst many more existing theories in the literature. The first one relates to time. This thesis is a work that should be performed in a limited time frame. There is therefore the need to limit its scope to only a few theories. Further work could look into how additional theories could possibly fit with the work that is presented in this thesis.

The second reason is related to validation. These theories are widely used and, for the most part, validated theories. They have also been used in an extensive number of case studies throughout the literature. Sabatier and Weible (2014) presents these theories along with how they were partially validated. Sabatier and Weible also present a comprehensive list of case studies that can be associated with each of the theories. This is particularly important as it removes the need for justifying the concepts presented in the theories and allows the author to use the concepts in this thesis. This limits the scope of the thesis.

## 1.3. Objectives and Research Approach

This section presents the objectives of the thesis along with the research approach that will be used to reach these objectives. There are two main objectives. The first one is to produce a conceptualisation that encompasses the four policy making theories considered (three streams theory, feedback theory, advocacy coalition framework and diffusion theory). This conceptualisation should outline the different common concepts and the differences between the different concepts in the four theories.

The second objective is related to the modelling. The aim is to adapt this conceptualisation, through a formalisation, into an agent based model for the three streams theory and the advocacy coalition framework. A thorough analysis should be made of the results obtained from this model to verify that the behaviours expected from the policy making theories can be found within the results of the model.

### 1.3.1. Research Question

Following these objectives, it is possible to formulate the main research question. This question is to be answered by the work performed in this thesis. It is given as follows:

*To what extent can a formal simulation model represent the policy emergence process theories?*

To answer this research question, three sub-questions are formulated:

1. What conceptual model can be made which would cover the largest possible intersection of all the aforementioned policy making theories?
2. How can this conceptualisation be formalised such that it be implemented in a simulation model?
3. How does the proposed formalisation advance the study of the policy emergence process as it relates to the four theories analysed?
4. Can the model simulated capture the dynamics hypothesised in the policy making theories? What are its limitations?

### 1.3.2. Method

To answer the first two research questions, a literature review is performed. This review aims at getting a better understanding of the theories that are considered for this thesis. Using this review, it is possible to produce a conceptual model and formalise this model through the concept obtained from the theories.

The two subsequent research sub-questions are also answered together. They are answered through the implementation of the formalisation into an agent-based model and its simulation. This implementation is done using Python as will be explained later on. Finally, to examine the usefulness of the model to answer the sub-questions, several experiments are designed. The results are then analysed to see whether the behaviours expected from the policy making theories, but also the conceptualisation and formalisation are obtained.

### 1.3.3. Scope

The scope of this work is limited to the conceptualisation and creation of a model to study policy emergence based on several policy making theories. The work will not look into the validation of these policy making theories in and of themselves, though it will look at the validity of their translation into an agent based model. The aim is only to try to reproduce expected behaviours from the model.

### 1.3.4. Scientific relevance

Several aspects make this work innovative and relevant scientifically. First, it is an attempt to grow the toolkit that policy scientists can use to analyse different cases. Currently most of the case studies are analysed using qualitative methods. The model developed here would also allow them to obtain a more in depth look at their case study. It would also allow them to test which changes could have made the most difference in the ultimate outcome. This model would also allow researchers to compare case studies in varying countries.

The second aspect relates to the use of agent based models. This growing modelling discipline has been under-utilised within the context of policy emergence. The work presented in this thesis will therefore help grow the family of agent based models.

Finally, the work presented here can also be used for a priori assessments. Current approaches of the evaluation of policy instruments tend to only focus on the technical and implementation phases to assess these policy instruments. The model proposed here will also allow researchers to consider the political aspects of the introduction of a new policy instrument, increasing the chances of considering successful instruments.

## 1.4. Structure of this thesis

This thesis is composed of two main parts. The first part look into the model formalisation. In this part, Chapter 2 presents a complete literature review of the four policy making theories. Chapter 3 then introduces the conceptualisation. This conceptualisation first outlines a common core for all the theories before detailing how each of these theories fits within the common core. The validation of the conceptualisation is also presented within this chapter. Finally, in Chapter 4 the entire formalisation, based on the conceptualisation, is presented. This formalisation presents the model as it is used within the code that is developed later on in the report.

The second part of this thesis deals with the model implementation, simulation and the analysis of the results. In Chapter 5, the model implementation is outlined. In this chapter, the world model to which the policy emergence model is coupled is explained along with the reason behind the use of agent based modelling and the use of Python. Chapter 6 presents the different experiments that are considered for the simulation of the model. Chapter 7 presents and explains the different results obtained. The exploration is first outlined followed by the different experiment results. The results show a mixed outcome with success in the policy emergence implementation but issues with the implementation of the world model. Finally in Chapter 8, this thesis is concluded with a discussion answering the different research question and presenting the strength and limitations of the mode presented.

# I

# The Model Construction

# 2

# Literature Review

The field of policy analysis originates from operations research and system analysis (Enserink et al., 2013; Walker, 2000). It slowly evolved from the 1940's until the 1960's into policy analysis. In the early days, policy analysis was mostly the study of cases (Heclo, 1972). Researchers looked at famous cases such as the Cuban missile crisis and analysed the decisions that were taken (Allison et al., 1971). The field then evolved into a field where policy analysis is for public policymaking. By that, it is meant that policy analysis is the use of methodologies or tools that are meant to help within the framework of policy making. Nowadays, the field has evolved in representing both aspects: case studies and tools and methodologies (Enserink et al., 2013). This thesis focuses on the latter part and does not look at a specific case study.

In the literature, several meaning are proposed for policy and policy analysis (Heclo, 1972). Policy is sometimes viewed as a form of a more generalised decision-making. Other times it is seen as a proposed course of goal-oriented actions within a given environment providing obstacles and opportunities (Friedrich, 1963). Ultimately, Heclo (1972) states that "the term policy needs to be able to embrace both what is intended and what occurs as a result of the intention". Bots (2013) also argues that the objective of a policy analysis is to change the mind of people. The argument is made that during the policy process, the minds of the different actors, ranging from the policy client to the scientists, are changed.

Overtime several 'models' have been presented attempting to represent the process of policy making and policy analysis. Enserink et al. (2013) cites five of these models which can be considered as the models on which other models are based. The first one mentioned is a model based on rational thinking. The model argues that the actors present during the process of policy making are rational, that the process evolves incrementally in a closed and hierarchical setting (Lindblom, 1959). This model suggests a linear process where failure to achieve a policy can be caused by the failure to fulfil one of the steps of the policy process. This policy process is expressed by Fischer (1989) as using the following steps: agenda formulation, policy formulation, adoption, implementation and evaluation. Criticisms related to this model are mostly related to the assumption of rationality from the part of the actors.

The second model presented is the view that the policy making process is a political game. It assumes that the actors are autonomous but interdependent and must make political compromises. The entire model suggests a bargaining game between the different actors (Lindblom, 1965). This approach has been supported by crises such as the Cuban Missile crisis mentioned above. It can also be seen in a lot of political spheres where politicians play a power game to get almost any policy through their respective institutions. The model suggests that the only way to get a problem solved or a policy adopted, the actors have to come to an understanding. If no understanding is achieved, then nothing will happen. This bargaining can be facilitated by brokerage efforts or arbitration for example (O'Toole Jr, 1988).

The third model views policy making as a discourse. The policies considered require a shared meaning between the actors. This can happen following a learning process. Such arrangements happen when different advocacy coalitions come together. This theory is the basis for the advocacy coalition framework that is detailed later on in this chapter (Jenkins-Smith et al., 2014). Failure to achieve progress within this model is due to the different coalitions not being able to get through to each other. Within the context of this model, Hall (1993) describes three orders for change of policies: first, second and third order. He states that first order changes are regular low level change affecting the setting of policy instruments. Second order changes are less frequent and relate to changes of the policy instrument itself. Finally, third order changes are rare and relate to major political events. He calls such event paradigm shifts which lead to large upset in the policies already in place. He argues that such changes are mostly due to the public and the policy makers while first and second order changes relate to policy learning from the part of bureaucrats.

The fourth model presented is the garbage can model (Cohen et al., 1972). The approach followed by this model is a messier approach where progress is the result of the opening of a policy window (where there is a coupling of the problems, policies and the actors). This approach is very fragmented and can be dependent on the informal networks of the different actors. This theory is the basis for the three streams model which is detailed later within this chapter. Successful policy change is dependent on the ability to bring together the three streams (problem, policy and politics) to come together at the right moment.

The fifth and last model presented relates policymaking to an institutional process. Policies are considered to be reproductions of earlier solutions. This model is set within a set of formal and informal rules. This model is part of new institutionalism theory. Within this theory, Williamson (1996) differentiates between four layers of institutions: organisations, inter-organisational arrangements, formal institutions and informal institutions. The success of policies within this model is related to an abundance or lack thereof of shared institutional arrangements.

This report outlines the different theories in more details. The three streams theory is presented in Section 2.1 followed by the feedback theory in Section 2.2. The advocacy coalition framework is then explained in Section 2.3 with diffusion theory in Section 2.4. The policy entrepreneurship, a model approach related to the three streams theory and used widely within this thesis, is also presented in Section 2.5.

## 2.1. The Three Streams Theory

The streams theory is a framework which attempts to explain how policies are chosen at a high level, national or supranational, under a condition of ambiguity (Herweg et al., 2015; Kingdon, 2003; Sabatier and Weible, 2014; Zahariadis, 2007). This framework is a derivative of the garbage can model where it is assumed that there is no beginning and no end within the decision process (Cohen et al., 1972). In the garbage can model, it is assumed that no one controls the policy process and the number of opportunities for a policy to rise. The agenda is set by the garbage content present in the cans. The cans contain four different streams: policy, problem, participants and choice opportunity. A problem becomes of importance usually due to a focusing event. This leads to a policy window which occurs when all three streams are coupled (Mucciaroni, 1992).

The streams theory follows the same principle. It also contains three streams and has the concept of policy windows. The main difference relates to the definition of ambiguity. Kingdon (2003) provides three indicators for ambiguity: fluid participation, problematic preferences and unclear technology (Zahariadis, 2007). The fluid participation refers to the fact that policies but also policy makers come and go within organisations and governments. Problematic preferences refer to the fact that people do not know what they want. Their decisions are often forced by time constraints. The technology illustrates that policy makers are usually not fully aware of their responsibilities with respect to the larger organisation's or government's goals.

The streams theory identifies three streams: policy, problem and politics (Zahariadis, 2007). The policy stream is made of a sort of soup. In this soup, one can find policies that are devised by specialists. From a large amount of policies, only a few are ever considered by the policy makers. Within this stream, these policies can also be recombined or arranged together to create new policies. The policies are selected by the policy makers based on different criteria such as the value acceptability, the technical feasibility and the integration (relating the different actors and the policy selected).

The second stream is the problem stream. It is composed of four main parameters: the indicators, the focusing events, the feedback and the load (Zahariadis, 2007). The indicators are policy specific characteristics that help the policy makers decide on the seriousness of a problem. Focusing events can help pick up specific problems. Such an event could be for example a train accident. This would lead politicians to pick up the problems related to train safety. Feedbacks relate to the fact that previous policy decisions might lead to new problems. Finally, the load relates to the fact that policy makers are unable to address a large amount of problems at once, they can only provide attention to several specific problems at once.

The third and last stream is the politics stream. Within this stream, the actors present in the decision making process are considered. This theory focuses on two main actor types: the policy makers and the policy entrepreneurs. The policy entrepreneurs cannot make any decisions. Their only strength is that he can convince the policy makers to make certain decisions. The policy entrepreneurs can be seen as lobbyists to the policy makers. They also operate to try to get the three streams to couple so that a policy window opens. It is then their task to convince the policy makers to choose specific policies when the policy window is open. On the other hand, the policy makers are unable to affect the streams. They are only responsible of taking decisions. These decisions are influenced by their personal situation but also by the party to which they belong, by the policy entrepreneurs, by the general public mood and by time.

Three main assumptions should be taken into account when using the stream theory (Zahariadis, 2007). The first one is that the different streams are independent of each other. They do not interact with each other and operate in parallel. The second assumption relates to the policy makers. It is assumed that the policy makers have only finite attention or processing power. This means that they cannot consider multiple policies at once, instead they have to focus their attention on specific policies. This can be considered analogous to the load concept in the problem stream. Finally, the third assumption relates to the fact that policy makers are under strict time constraints. They have to decide on a certain policy quickly before policy windows close. Their policy choices can be affected by this time constraint.

The streams theory has been used in multiple case studies. For example, Ackrill and Kay (2011) used the theory to study the sugar reform in the European Union (EU). This application helps extend the work from Kingdon as the streams theory was originally devised with the United States in mind. Applying the theory to the European context did require some adjustments like the decontextualisation of some concepts. Other concepts had to be reinforced as they are more present in the EU. This is particularly important for the policy spillovers which are very present in an institution like the European Commission. The streams theory has also been applied on emission trading policy in Germany in Brunner (2008) where it was found not to be sufficient to understand the case study, or to study the smoking ban in the UK in Cairney (2009).

Some questions do remain when considering the streams theory. The first one relates to the way the policy makers are considered. The current theory does not consider the in-depth psychology of the policy makers. It does not consider the fact that their decision could be affected by things as small as their popularity at a certain point in time or by irrational decisions (Mucciaroni, 1992). Furthermore, one could question whether the three streams being considered are indeed really independent in real life. Some academics disagree with this view. They argue that in some cases, the streams can be considered interdependent. Finally, some concerns also remains with respect to the verification and the validation of the hypotheses used to construct the theory. Considering this is a mostly qualitative method, one cannot use statistical tests to verify or validate the results of the theory (Bendor, 2001).

## 2.2. The Feedback Theory

Newly implemented policies are not implemented in a vacuum. They are usually preceded by other policies and supplemented by others. One can therefore expect that policies being implemented will have an impact on future policies and will be impacted by already existing policies. This is referred to as the feedback effect, (Mettler and Soss, 2004; Pierson, 1993). These feedback effects not only have an impact on other policies but can also have an impact on the decision making process, affecting the policy makers, the general public, as well as institutions and policy entrepreneurs.

In the theory, four main inquiries are used to describe the feedback effects (Mettler and SoRelle, 2014). The first one regard the meaning of citizenship. Some of the policies enacted by the policy makers can have a profound impact on what it means to be a citizen in a certain country. These policies can affect the status of citizens in the general public. This happens through policies which differentiate different types of citizens. These policies can be related to immigration or naturalisation. This can in turn shape the political landscape. For example, policies affecting the immigration process can favour certain political parties because of the large influx of certain population or alternatively reinforce opposing parties due to the rejection of these migrants by the local population. This is the case for voter ID laws in the United States for example (Hershey, 2009).

The second one is related to the form of governance. These are policies that might lead to a reduction of the power the policy makers have. It can also lead to a change in the administrative arrangements for new policies. These policies can have an impact on how policy makers approach new policies or how they make their decisions on future policies. This is of course affected by whether the feedback effect stemming from these policies are negative or positive. For example, in the United States, the Social Security Administration, once unpopular, gained a favourable reputation. After becoming more popular, it was used to deliver other policies (Derthick, 1979).

The third inquiry concerns the power of groups. In the jargon used for the streams theory, one can consider these groups as being policy entrepreneurs. Although external groups are usually considered to originate entirely externally, in practice it can be demonstrated that most groups are actually established once a policy has been put in place. These groups will either try to defend the policies when new policies are being considered or will try to reduce its impact. New policies can also strengthen or weaken the position of the policy entrepreneurs.

The fourth and final inquiry relates to the political agendas and the definition of the policy problems. Some of the policies that are decided on by policy makers will ultimately affect what policies the policy makers will be addressing or will be allowed to decide on. New policy issues might be within the jurisdiction of the policy makers while other will move out. Some policy issues can also bring different types of coalition of policy makers to the table. Finally, new policies might affect the importance of some of the policies to the policy makers. They will want to create new policies right after or attempt to protect the existing policy at all costs by preventing new policies from being enacted.

There are different mechanisms that lead to the feedback effects mentioned above. Two are isolated in the literature: the resource effect and the interpretive effect (Pierson, 1993). The first effect is related to policies which affect the public monetarily. Some policies might increase the taxes while other provide subsidies to specific classes of citizens. These policies are likely to have a resource effect which means the public's participation will be affected in the successive public discourse. The interpretive effect relates to the rules that new policies establish. The way the new policies are designed and implemented will affect the public. Depending on how they are affected, their participation to the public discourse will be again affected.

The feedback theory has been used to attempt to explain real life cases. For example, this is the case in Jordan (2013) where feedback theory is used to study the welfare system. The theory was used in this case to explain the effect of welfare on consequent policies. This study was a comparison performed in different countries. Another case study is Mettler (2002) which studied the effects of the G.I. bill at the end of World War II. It explains why the G.I. bill had such a profound effect on the United States and provides a framework to study other policies.

## 2.3. The Advocacy Framework Coalition

The Advocacy Coalition Framework (ACF) is a theory of policy change (Moyson et al., 2014; Weible et al., 2009). It was developed initially by Sabatier and Jenkins-Smith (1993) to attempt to explain and simplify the complexity of the policy making process. The ACF sees the policy environment as split in different policy subsystems. These subsystems are considered separately from each other and can represent concepts such as security or health

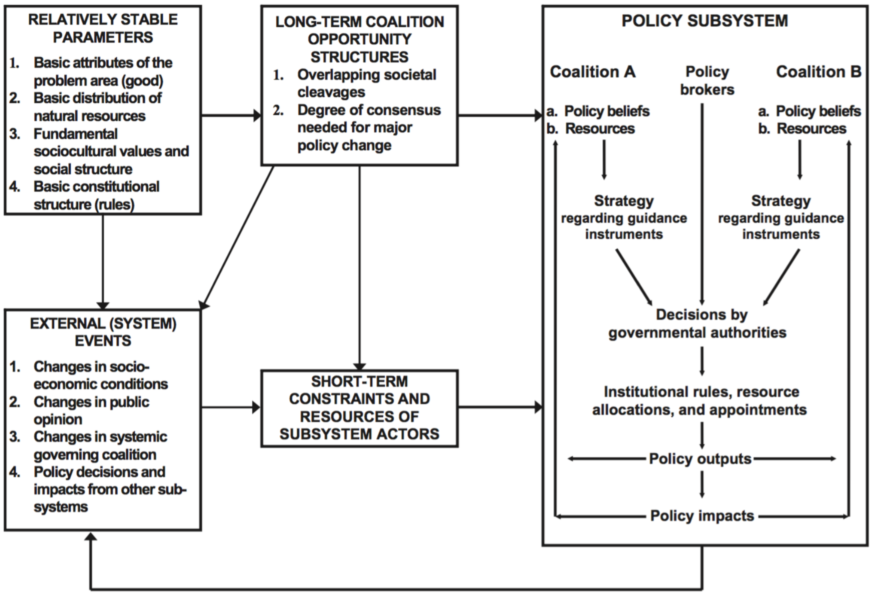


Figure 2.1: The 2007 advocacy coalition framework diagram, Weible et al. (2009).

for example. In each of these subsystems, the actors are organised in coalitions. These coalitions are assembled with actors sharing similar beliefs. Within the subsystems, the coalitions attempt to influence each other. The ultimate goal is that these coalitions can influence the policy makers to change the policies based on their respective beliefs. The policy change is therefore a reflection of the dominant position in the subsystem. The principle of the ACF is summarised in Figure 2.1.

There are several assumptions that are needed to define what a subsystem is, according to Sabatier and Jenkins-Smith (1993). The first one states that the policy subsystem is the primary unit of analysis for understanding the policy process. The second assumption states that these same policy subsystems demarcate the actors on a given policy topic. Thirdly, the policy subsystems are considered to be semi-independent but can occasionally overlap. Fourth, the subsystems provide authority which can be used to alter the status quo. The fifth and final assumption states that the subsystems can undergo stasis periods, incremental change period or major change periods.

Some assumptions are also specified for the actors participating in these subsystems. The actors are considered to be rational. They can only process a limited amount of information. They are motivated by their own beliefs and can experience the so-called “devil shift”. This is the belief that your opponent has more resources and is more powerful than you are. The belief system of the actors within the ACF is characterised in three parts (Sotirov and Memmler, 2012). The first and highest tier of this belief system is composed of the deep core beliefs. These beliefs are normative and ontological axioms. They are beliefs that will change only over very long periods of time if at all. The core beliefs are not specific and therefore apply to all policy subsystems. The second tier is composed of the policy core beliefs. These are beliefs that the actors have on specific policy subsystems. These are more likely to be swayed during argumentation with other actors or coalitions. Finally, the third tier beliefs are the secondary beliefs. These are more detailed and only focus on specific details of the policy subsystem. These can easily change depending on the desired outcome for the policy.

As mentioned earlier, the actors are placed together in coalitions within the policy subsystems. Decision for policy change are made between these coalitions. Several assumptions are provided by Sabatier and Jenkins-Smith (1993) about these coalitions. First, when a major controversy occurs, the line-up of allies and opponents tends to be rather stable over a decade or so. Second, the actors within a coalition will show substantial consensus on issues pertaining to the policy core, although less so on secondary aspects. Third, an actor (or coalition) will give up secondary aspects of its beliefs before acknowledging weaknesses in the policy core. Fourth, within a coalition, administrative agencies will usually advocate more moderate positions than their interest group allies. The fifth and final hypotheses states that actors within purposive groups are more constrained in their expression beliefs and policy positions than actors from material groups. Note that each of these hypotheses have been validated to different degrees (Sabatier and Jenkins-Smith, 1993).

Within the ACF, the actors might want to initiate change in the policies. This is usually done following four paths: external events, internal subsystem events, through negotiated agreements and policy-oriented learning. External events can be shocks or perturbations that are outside the control of the subsystem participants. They can also be a change in the political environments which will affect the policy subsystem. The internal events are events that occur within the boundaries of the policy subsystem. These are likely to influence the beliefs of the coalitions. For the negotiated agreements, nine prescriptions were defined by Sabatier and Jenkins-Smith (1993) as: a hurting stalemate, broad representation leadership, consensus decision rules, funding, commitment by actors, importance of empirical issues, trust, and a lack of alternative venues.

Policy-learning is one of the reasons for which change could happen. This usually happens incrementally over long periods of time. Policy-oriented learning serves as an enlightenment function for the different coalitions. Six hypotheses were specified for the policy-oriented learning by Sabatier and Jenkins-Smith (1993). First, policy-oriented learning across belief systems is most likely when there is an intermediate level of informed conflict between two coalitions. Second, learning across belief systems is most likely when there exists a forum that is prestigious enough to force professionals from different coalitions to participate and which is dominated by professional norms. Third, quantitative problems are more conducive to learning across belief systems. Fourth, problems involving natural systems are more conducive to policy-oriented learning across belief systems than those involved purely social or political systems because, in the former, many of the critical variables are not themselves active strategists and because controlled experimentation is more feasible. The fifth and final hypotheses states that even when the accumulation of technical information does not change the views of the opposing coalition, it can have important impacts on policy by altering the view of the policy brokers.

Heikkila and Gerlak (2013) also details the different phases of the policy learning process: acquisition, translation and dissemination. In the acquisition phase, the actor will attempt to gain knowledge about a specific policy. The actor will look for opportunity from its environment and seek information from other actors through group dialogue both formal or informal. During the translation phase, the actor will evaluate the knowledge s/he has gained and search for more internal information. In a way, this is the part where the actor interprets the information gained from the outside. Finally, in the dissemination phase, the actor will actively seek to disseminate the information gained. Heikkila and Gerlak (2013) mentions several two main products of policy learning: cognitive changes (of the beliefs of the actor) and behaviour changes related to changes in strategies or policies. Several aspect affect this policy learning. They are the structure of the network in which the actors operate, the nature of the connections that the actor has with other actors (social dynamics) and the level of technicality of the field in which this learning occurs. As mentioned previously, external factors can also have a serious impact on the learning process.

The ACF is widely used for case studies (Hysing and Olsson, 2008; Nohrstedt, 2008; 2010; Radaelli, 1999; Ripberger et al., 2011). An example of the ACF is used in a study of the changes in swimming and track and field athletics in the United Kingdom and in Canada (Green and Houlihan, 2004). The ACF helped understand the dynamics at play in the two countries and how it resulted in the observed differences. Case studies were also used to adjust the framework as a whole as shown in Leifeld (2013). In this case, the study was about German pensions. This study looked into the polarisation of the parties involved in a coalition leading to its split.

The ACF remains a framework that is being continuously researched on. Several of the hypotheses and the assumptions are not yet fully validated. This is due both because of time but also because some of these hypotheses are hard to effectively validate. The theory is currently re-evaluated as shown in Gupta (2012), Ingold (2011), Sotirov and Memmler (2012), Witting (2012) and Weible et al. (2009). These different papers attempted to validate some of the hypotheses and assumptions made by Sabatier and Jenkins-Smith (1993). For this, they surveyed dozens of publications. They made some changes to the original hypotheses and assumptions based on these surveys. However, there still remains hypotheses that cannot or have not been validated maintaining the advocacy coalition framework as a work in progress.

## 2.4. The Diffusion Theory

According to Stokes Berry and Berry (1999), there are two ways that a policy can change. It can either change because of internal determinants or it can change because of diffusion. Internal determinants related to the fact that innovation is driven by the government due to political, economic or social factors.

The diffusion theory assumes that innovation and policies can be communicated through certain channels over time. This diffusion is usually studied when it happens between different governmental entities. Diffusion happens if the probability of adoption of a policy by one government is influenced by the policy choices of another government. Five mechanisms of diffusion have been identified in the literature.

The first mechanism is the learning mechanism. It is fairly similar to the policy-oriented learning presented in the ACF in the previous section. Government A will derive information about the effectiveness of a certain policy from government B. If they consider this policy to have been successful enough, they might decide to apply it for themselves.

The second mechanism is imitation. In this case, government A simply imitates the policy of government B. This happens because government A feels that the policy is worthy of adoption. The third mechanism is normative pressure. In this case, government A will adopt a policy from government B due to normative pressure. This can be because it sees that this specific policy is applied by a lot of other governments and they share the same normative values. This makes the policy interesting and worth looking into.

The fourth mechanism is competition. In this case, there might be a competition between two governments. One government might want to get an edge on the other and will implement a policy to get that edge. Two types of competition mechanisms are observed in literature: location-choice and spill over-induced competition. For location-choice competition, the government attempts to change the location of individuals who could go in any jurisdiction. In spill over-induced competition, the government adopts a policy in such a way that another governments policy's benefits are reduced.

The fifth and final mechanism of diffusion mentioned by Stokes Berry and Berry (1999) is coercion. This is a mechanism that occurs when a government forces a policy onto another. This can happen in the context of conflicts when a government will push the other to adopt a policy that might favour it for example.

Several methods have been devised to attempt to simulate these diffusions mechanisms (Stokes Berry and Berry, 1999). The first of which is called the national interaction model. This model simulates an entire society to see the spread of innovation through diffusion between the agents. Another is the regional diffusion model. In this model, the assumption is that the governments are influenced by other governments with which they share a border. In later versions of this model, this assumption was changed to include proximate governments also. The leader-laggard model is another model. In this model, the governments are classified in two main categories: the leaders and the lagers. The leaders are governments which are first to innovate while the lagers are governments that follow the leaders. Diffusion is then used to model the acquisition of the innovation between the leaders and the lagers. An important problem related to this model is that it is very difficult to validate as it is not always easy to fine which government is leading and which is lagging.

Diffusion of innovation is not only related to the concepts mentioned previously (Stokes Berry and Berry, 1999). Additional parameters need to be taken into account when modelling this theory. A special importance should be placed on the resources both economic and political. Certain policies might be pushed by entrepreneurs with little economic resources but with plenty of political one.

The diffusion theory has been used a lot in the United States, for example to describe the state lotteries as shown in Caudill et al. (1995). It has also been used to describe interstate competition in Berry and Baybeck (2005). Case studies present in the United States provide for good examples as diffusion is more likely to occur between states. The states tend to share similar norms so it easier to adapt policies from neighbouring states. This theory has also been applied to Indian states as shown in Bussell (2010) with the study of policies related to communication technologies. Once again this theory applies well to large federal countries as their states tend to share some of their norms and values making policy diffusion more acceptable.

Finally, one of the flaws of this theory is that it tends to consider policies as single entities (Stokes Berry and Berry, 1999). This is however most of the time not the case. Policies are composed of different components that can sometimes be split. Not all components have to be adopted by a new government. The government can choose to adopt one part of the policy or none of it. This is not well reflected within the diffusion theory which tends to consider the policies as a whole.

## 2.5. The Policy Entrepreneurship Model

The concept of policy entrepreneur is widely encompassing and recurrent within the four theories presented. Several models have been developed to describe the actions of the policy entrepreneurs within the policymaking arena. Mintrom and Norman (2009) presents five such models. Mintrom and Norman also state that policy entrepreneurs within each of these models share specific elements. The first element mentioned is the display of social acuity. This display of social acuity is channelled in two ways: making good use of the policy network and understanding other actors in the model. The second element relates to the definition of problems. Policy entrepreneurs have to be interested with how problems are defined if they are to achieve any change in policies. The third element states that policy entrepreneurs have to be ready to build teams. This allows them to show that they have a certain level of support for their interests. The final element is the fact that policy entrepreneurs have to lead by example. By this, it is meant that policy entrepreneurs should attempt to reduce the perception of risk for other actors. This can be done through the use of pilot projects for example. Note that this might not be feasible for all topics.

Mintrom and Norman (2009) shows that these elements apply to the five models presented earlier on in the introduction. Some of these elements are mentioned in the different policymaking models in the literature. There is a special interest in two policymaking models regarding this thesis. These are the three streams and the advocacy coalition framework models. Each contains the presence of policy entrepreneurs but approached in a different way. Mintrom and Vergari (1996) compares the two approaches. There are some important differences between how the policy entrepreneurs are approached in both models. The first difference relates to the scope of the policy entrepreneur models. The advocacy coalition is a system that consider the entire policymaking community. The three streams approach is narrower as it considers only how policy entrepreneurs promote their ideas to the policy makers. The time-frame is also very different between both approaches. The advocacy coalition clearly considers long periods of time (several decades) where the policy entrepreneur beliefs vary slowly. The policy entrepreneurship considers much shorter spans of time where change happens quickly to grasp opportunities. Although these two approaches have differences, case studies show that both approaches can be used to study specific examples. This is done in Mintrom and Vergari (1996) where the education reform in Michigan is analysed using both approaches. Brouwer et al. (2011) shows a similar result but for the case of Dutch water management.

## 2.6. Reflection

From this chapter, one can already see some commonalities between the different theories and identify some of the problems that will arise when considering a common approach to all the theories. The first aspect is that it becomes clear that the feedback and diffusion theories are theories that can be combined with the three streams theory and the advocacy coalition framework. Both theories relate mostly to instruments. The feedback theory looks at the impact of instruments on the policy arena. The diffusion theory looks at the impact of actors and instruments across policy systems.

Different concepts can be shown as being in common. This is the case for the actors that are considered in the theories. One can also see that some of the concepts presented in one of the theories can be transplanted to another theory to operationalise it. The first such concept would be the belief system presented in the ACF that could be used for the other theories to approach the agent's brains. The concept of policy learning from the ACF could also be used in the other theories to convey the belief dynamics that is needed for a model to see changes occur.

Finally, and this is the purpose of this thesis, the presentation of these theories does show a great lack of formalisation. The theories are described in qualitative ways with a lack of detail on how they could be operationalised. This will be the challenge of the work presented starting with the conceptualisation that is presented in the next chapter and the formalisation in the chapter following it.

# 3
# The Conceptualisation

This chapter presents the overall conceptualisation. A common core is first presented in Section 3.1. This common core uses several concepts selected from the different policy making theories to form a skeleton for the approach used to combine these theories. In Section 3.2, additional concepts required to obtain a three streams model are presented. This is done for the ACF in Section 3.3, for the feedback theory in Section 3.4 and for the diffusion theory in Section 3.5. Further on in this chapter, the justification of the use of these different concepts is presented in Section 3.6. This chapter is then concluded with the presentation of the validation that was performed on this conceptualisation in Section 3.7.

## 3.1. Common core

The policy emergence process is a process composed of several **iterative stages**. Different iterative stages can be differentiated. There are iterative stages where the **actors** present in the **policy arena** interact with each other. The policy arena is the environment in which these connected actors evolve. Additionally, different types of actors are present within the policy arena. They are the **policy makers**, the **policy entrepreneurs** and the **external parties**. The policy makers are the actors that have decision making power. This means that they can decide what is placed on the **agenda** or what **policy instrument** should be implemented. The former is performed in the round called the **agenda setting** while the latter is perform during the round called the **policy formulation**. They can also work to influence the **beliefs** of the other actors present in the policy arena which are connected to them through their **policy network**. The policy network is the network that connects the actors present in one policy arena. The actors are connected based on their awareness of one another. The likelihood of actors to interact with one another is dependent on their awareness of one another. Over time the policy network of the actors will deteriorate. To maintain their network, the actors are able to perform simple actions using their **resources**. These resources represent their financial and political resources.

Each policy maker possesses a belief hierarchy that defines its beliefs on the issues being discussed in the policy arena. This hierarchy is composed of field wide beliefs at the top and beliefs on increasingly detailed issues when progressing downwards in the hierarchy. Example of issues are public transportation or the amount of plastic present with a size less than 2 millimetres present in the oceans. For each of these issues, the actors have an understanding of the current **states of the world** and a goal for where they would like to see this issue be. Furthermore, each level in the hierarchy is connected to the next through causal relations up to the highest level. These causal relations help the actor understand how different issues affect each other and therefore how the world works.

The impact of the influence of the policy makers on the other actors is dependent on the resources spent by the policy makers, the difference in beliefs they have with the actor they are influencing and the affiliation of both influencing and influenced actor. However, before influencing other actors, a decision must be made on what influence should be performed and on which actor. For this, the agent will assess the different possible action according to their expected impact on the **urgency** of the issues. This urgency is determined by the actors based on the gap between the current states of the world and their aim and also in relation to the impact that this issue ultimately has on their normative beliefs. The ultimate goals of the policy makers being to reach their normative belief goals. This assessment will vary depending on their **political affiliation** in relation to the affiliation of the actor influenced, their perceived **conflict level** on the issues concerned with the actor influenced, their policy network (awareness level) and whether the actor being influenced is a policy maker or another actor. Within the policy arena, actors will prefer influencing policy makers as they have decision making power (they decide on the agenda and the policy instrument to be implemented). The political affiliation of the actors relates them to specific **constituencies**. Furthermore, it affects the likelihood of actors of different affiliation of influencing one another. The resources available to the policy makers are dependent on the size of their affiliated constituencies. There is a conflict level for each issue represented in the beliefs of a policy maker. This conflict level is the difference in the views of the world of the policy maker and what the policy maker thinks the beliefs of the actors influenced are. This perception of actor B's beliefs by actor A is referred to as the **partial knowledge** of the actor A. The amount of conflict level will affect the likelihood of the two actors interacting with one another about certain issues. Actors are more likely to discuss issues for which they have a mild conflict level and less likely to discuss issues for which they have a high conflict level.

There are different types of actions which the policy makers can perform on the other actors. They can perform **framing actions**. These actions are attempts to influence other actors on their beliefs of how the world works (the causal relations in their beliefs hierarchies). The policy makers can also **directly influence** the actors on their beliefs for the issues. They can influence them on their way they see the world or on their aims of what the world should be. Because the **attention span** of the actors in the policy arena is limited, these actors tend to only influence other actors on one selected issue. This issue is selected based on the appearance of urgency.

The partial knowledge of the actors is updated whenever an influencing action is performed. Both the actor influencing and the actor being influenced have interacted and therefore get a better, but not perfect, understanding of each other's beliefs on the topic of the interaction.

As mentioned earlier, the policy makers can also decide what is on the agenda. This is done by selecting the issue that they consider to be the most urgent to them. The issue that is ultimately placed on the agenda is the issue that most policy makers believe is urgent. The choice of issue on the agenda will go on to define which issues can be discussed in iterative stages looking at lower level issues in the belief hierarchies. The issues all have to be related to the issue on the agenda. This is however subjective to the actors depending on their personal beliefs. The process of agenda setting therefore helps narrow down the problems observed by the policy makers and to ultimately decide on a **policy instrument** that can be used to address such problem.

The policy entrepreneurs are actors that seek to influence the beliefs of the policy makers primarily but also to influence the beliefs of the other actors within the policy arena through their policy network. Their aim is to push their beliefs onto the other actors present in the arena. Similarly to the policy makers, the policy entrepreneurs have a belief hierarchy, a political affiliation and use resources to influence other actors. These resources are also defined based on their constituencies. They can also perform different actions on the policy makers, external parties and other policy entrepreneurs. They can frame how the world works, influence on the beliefs of other actor's view of the world and their goals. The likelihood of performing an action and its actual impact are determined in a similar way as for the policy makers.

The external parties are actors that have multiple roles within the policy arena. The external parties represent actors such as the media, but also research institute or academic institutions. They help inform other external parties, the policy makers, the policy entrepreneurs about the current state of the world. They can also influence other external parties, policy makers and policy entrepreneurs on their beliefs of how the world works. Finally, they can influence the goals of the constituencies. Similarly to the policy makers, the external parties have a certain political affiliation and resources stemming from that affiliation.

The external parties have direct access to the states of the world. They can therefore transmit this information to the actors within the policy arena along with the constituencies. However, not all external parties are interested in all states of the world, some external parties are only interested in specific states. Furthermore, this transmission of the states is dependent on the policy network, and the affiliation of the external parties and the actors to whom they are transmitting this information. Different actors will perceive the external parties as more or less trust worthy depending on their affiliation.

The external parties can also influence other external parties, the policy makers and the policy entrepreneurs. They can only do this through a framing action that affects all actors present in the policy arena called blanket framing. The likelihood of performing a framing action is defined the same way as for the policy makers. The impact is obtained as shown earlier on. The impact is however spread on all actors concerned.

Finally, the external parties can influence the goals of the different constituencies through blanket influence. This is similar to the blanket framing that is used on the actors within the policy arena but this time they affect the others' goals. The likelihood of an action being performed will depend on the difference in beliefs between the constituencies and the external party concerned and the affiliation of the external party performing this action. The impact will depend on the resources spent and the difference in beliefs.

Each constituency represent a sector of the electorate and is associated to a political affiliation. Each constituency represents a certain percentage of the total voter population. This representativeness of a constituency is what affects the amount of resources that is distributed to the different actors within the policy arena as mentioned previously. The constituencies can influence the policy makers present in the policy arena. The policy maker's goal beliefs tend to move towards the goals of their constituencies to increase their chance of remaining in office.

A second round can also be identified as a policy formulation round. In this round, the aim is to adopt a policy instrument based on the chosen agenda such that it is implemented in the world. Policy instruments are the specific mechanisms policy makers put in place in order to impact the issues discussed within the iterative stages. During the policy formulation round, the actors influence each other's beliefs similarly to the agenda setting round. The aim here is however different. Each actor selects a policy instrument based on its expected impact in the world. This impact is assessed by the actors based on their beliefs of the change the instrument will have on the states of each issues compared to their own goals. Because the actors have a limited attention span, they can only select what they perceive as being the most appropriate policy instrument. They decide that based on the impact that the instrument have on their beliefs and based on which issues need to be addressed the most urgently. The interactions of the different actors are the same as for the agenda setting round. The likelihood of an action happening is however now determined based on the expected impact that each instrument has on the urgent issues in the actors' beliefs within the narrower field of issues selected in the agenda setting stage.

One main difference is that the policy formulation round does not end with the selection of an issue but the selection of a policy instrument. Furthermore, the policy instrument selected is only implemented if the number of policy makers that support that instrument is superior to the threshold required for the implementation of the instrument. This threshold can be a majority, a two third majority or unanimity.

The last round considered is a round that does not involve the actors. It is the world. In this round, the instrument that has been selected is implemented. The world is affected by that instrument and the states of the world change accordingly. This then has an impact on the belief of the actors present in the policy arena as the change in the states is conveyed by the external parties to the different actors.

Finally external events can be introduced in the model. Such external events can affect anything from the goal of specific agents for a specific issue to a new distribution of the constituencies. These external events are devised based on case studies. The modeller must then adopt the impact of an election into the model's framework to appropriately represent that election.

## 3.2. Three streams theory

The introduction of the three streams theory changes some of the aspects presented in the common core. These changes are performed to account for the concept of streams and of policy window. The iterative stages considered are the same as the iterative stages mentioned in the common core. The difference is present in what the actors present in the policy arena choose as an issue. The actors can now choose from a policy or a problem as called for in the three streams theory. The problems are obtained in the belief hierarchy of the actors while the policy are obtained in a **policy hierarchy**.

The policy hierarchy is a hierarchy containing policy instruments. These policy instruments have specific impacts on the issues present in the belief hierarchy of the actors. The concept of policy instrument is therefore the same as the one presented in the common core. Within the three streams theory, policy instruments are present in all iterative stages. Each of these impact is now subjective which means that they also represent beliefs on the effectiveness of the different policies. These beliefs can also be influenced by the different actors present in the policy arena.

Each actor first selects a policy or a problem. The problems are graded similarly to what was previously presented in the common core: based on the perceived urgency of the chosen issue. The policy are graded based on their impact on their associated issues. Whichever grade is the highest will be chosen by the actor. If the actor chooses a problem first, then s/he will have to choose an associated policy based on the effectiveness of the policies. Furthermore, all actions performed by that actor from now on will be on the beliefs of other actors concerning the selected problem. These actions are the same as the ones in the common core. If an actor chooses a policy first, s/he will have to choose an associated problem based on urgency. Similarly to the problem, all actions performed by that actor from now on will be on the beliefs of other actors concerning the selected policy.

The policy actions are similar to the problem actions presented in the common core for the different actors but with one change to the framing actions. The aim of the actor is now to affect the impact beliefs of other actors in their policy network. The actions on policies are therefore akin to the framing actions related to the problems. This can only be done by actors having first selected a policy as mentioned earlier. There are some important caveats to this approach. First, the constituencies do not possess any beliefs on the policy hierarchy. This means that external parties cannot influence the constituencies if they have selected a policy first, they will then move on to their problem (which they selected based on the policy first chosen) and influence the constituencies on that problem. Second, the constituencies cannot influence the instrument hierarchy of the policy makers, the influence remains focused only on the belief hierarchy.

Additionally to the introduction of streams, the policy entrepreneurship model which is tied to the three streams theory introduces the concept of **teams**. Teams are small, short-term groups of actors which try to influence other actors on a specific problem or policy. These teams are constituted by actors when they consider that a policy or a problem is very urgent and when they can find other actors that share their beliefs on that policy or problem and the urgency of it. Once a problem or policy has been sufficiently pushed (enough actors have been influenced), then the team will disband and the actor will return to acting separately. Teams use the same actions as the individual actors. They provide actors with a larger policy network. This is because the team network consists of the sum of the networks of all actors present in the team. The teams obtain their resources from their members based on their feeling of belonging within a team. The actions performed by the team have to be agreed by the entire team as team are non-centralised entities. This means that no actor is powerful enough to impose his/her will on the other actors. Teams can also perform influencing actions on their own members. This helps increase the cohesiveness of the team so that they can last longer within the policy arena. The actions performed by team members on team members are blanket framing, influence on goals an influence on states.

Although there are also a set of iterative stages in the three streams theory, the actions performed in both iterative stages are not different anymore. Because each actor must have chosen either a policy or a problem, the actions are exactly the same in both iterative stages for all actors present in the policy network. The difference remains in the fact that for the agenda setting iterative stages, an agenda is set at the end which defines what is discussed thereafter. The agenda is composed of a problem and a policy. Each is chosen as being the most selected by the policy makers. The problems and policies discussed thereafter must relate to the problem and policy on the agenda. They must therefore be on a lower level in their respective hierarchies. For the policy formulation, the policy instrument chosen by the policy maker is the one that meets the threshold requirement once again. This disregard the fact that a policy maker might have chosen a problem first.

## 3.3. The advocacy framework coalition

The introduction of the advocacy coalition framework adds some different changes to the common core. The main addition is the concept of **coalitions**. The coalitions are groups to which actors are assigned based on their normative beliefs. They are long term entities that perform actions on other actors or other coalitions to influence them into similar beliefs. Actors only change coalitions when their normative beliefs vary which happens only rarely. The actions performed by coalitions are similar to the ones performed by teams. However, coalitions are centralised entities. This means that the **coalition** leader is the only actor that decides which actions are implemented. The coalition leader is the actor within a coalition that has the largest policy network. Finally, the number of coalitions present within a policy arena is usually limited to only a few according to the literature.

The ACF also introduces the policy broker. Policy brokers are actors that look in their network to put in contact actors which are badly connected within the policy arena. Policy makers, policy entrepreneurs and external parties can all be elevated to the role of policy broker which grants them additional actions. Two actions are added. With the first action, the policy broker can connect two actors which are not connected (but to which s/he is connected). In the second action, the policy broker can raise the awareness level between two actors (if his/her own awareness level is high enough). To perform these actions, the policy brokers is provided with additional resources fitting with the strength of his/her policy network.

Finally, which action is chosen by the policy broker is decided based on the type of policy broker. Neutral policy brokers will select the actions that will lead to the largest impact. This means that connecting actors that are not yet connected will come first, followed by raising the awareness between actors that are already aware of each other. If the policy broker plays an advocacy role, then s/he will select actions with actors that share his beliefs.

## 3.4. Feedback theory

For the feedback theory, the policy instruments implemented by the actors are supplemented with feedback effects. The feedback effects have an additional specified effect on different parts of the world or of the policy arena. When choosing for a policy instruments, the actors are not aware of the feedback effects. There are three feedback effects considered.

Some feedback effects have an impact on the constitution of the constituencies. The percentage distribution of each constituency will be affected. Some feedback effects have an impact on the belief hierarchy of the actors opening new issues to consideration in the hierarchy or removing others. Finally, a third feedback effect relates to the link between constituencies and the resources of the actors within the model. This links is affected by this type of feedback effects.

## 3.5. Diffusion theory

The introduction of the diffusion theory requires the consideration of multiple policy subsystems. These subsystems can represent different nations or cities for example but they are all regarding the same issues. The diffusion theory specifies the impact that the actors in a subsystem might have on actors of another subsystem. The subsystems share specific relationships ranging from **friendly** to **competitive** while considering **coercive** and **dominant**. These relationships help define the actions that can be considered between the actors of the different subsystems. Each subsystem also possesses a certain **status**. This status helps define the amount of resources that is provided to each of their actors.

The actors in the different subsystems are all part of a **super-policy network**. This network connects actors between the different subsystems. Through this network actors can influence each other depending on the relationships between the arenas. An actor will consider all possible actions. The actions that results in the most change in beliefs is considered most effective and is implemented.

The subsystems themselves are part of a network. Each subsystem has a link with another. Each of these links are one directional and can be of one type from friendly to competitive. Links that are coercive or dominant also gain a **strength** attribute. This strength attribute defines the influence that a subsystem will have on another when actors from one arena influence actors in the other. The actions that actors can perform is defined by the link that links their respective subsystems.

In the case of friendly relationship, the actor will be able to perform all actions that are available within the common core. These are actions of framing, influence on states and goals for the beliefs of the other actor. The likelihood of performing these actions along with their impact is assessed the same way as presented previously. When considering the diffusion theory with the common core or the ACF, then the actions are only performed on the issues. When it is considered with the three streams theory, then problems and policies actions are possible.

In the case of a coercive or dominant relationship, the actors will force their own goal beliefs onto selected actors in the other subsystem. The likelihood of this forced influence to be selected will depend on the conflict level between the actors and the type of actors that is being influenced (policy makers are more likely to be influence). Considering actions with an equal impact, actions on a dominant relationship will be most likely to happen, followed by coercive actions and finally friendly actions. The actual impact will only include the amount of resources spent, the difference in beliefs between the two actors and the strength of the considered subsystems. Once again, for similar actions, the impact will be largest in a dominant relationship.

In the case of a competitive relationship, the actors within one subsystem will seek to get a better world that the ones in other subsystems. To achieve this, they will change their goals to match the ones of other subsystems. This is also done through interactions. The likelihood of performing such an action along with their impact will is calculated similarly to the actions between friendly subsystems. The main difference with respect to the impact is that the impact of the actions are on the actor performing the action (the actor influences him/herself based on the beliefs of an actor in another subsystem).

## 3.6. Justification

The overall conceptualisation makes a number of assumptions. The justification for these assumptions is presented within this section. They are split in three main types. First, there are the assumptions that are based on the literature and directly on the theories. Then there are the assumptions that are made based on common sense and what can be observed in the political arena on a day to day basis. Finally, there are assumptions that are used as modelling choices. Most of the assumptions used are a mix of all three types.

There are several assumptions that are taken directly from the ACF literature (Jenkins-Smith et al., 2014; Sabatier and Weible, 2014; Weible et al., 2009). Such assumptions are for example the assumption that policy makers have decision power but that they can also influence the beliefs of other actors. This latter assumption is based on the fact that policy makers, from a modelling perspective, are also policy entrepreneurs and are not just passive actors that can only be influenced.

The belief hierarchy is largely a result of the ACF literature too. It uses a tiered structure as presented by Jenkins-Smith et al. (2014). However, the additional structure provided to the issues within the hierarchy were added based on some of the literature, common sense and due to modelling choices (Holsti, 1962; Matti, 2009). This is also true for the causal relations linking the different issues in the different tiers of the hierarchy. These different parameters are also the parameters that helped define the actions that the actors can perform. The literature in Mintrom and Vergari (1996) specifies that actors can frame one another but without much more details. This is extended in such a way that each of the parameters within the belief hierarchy can be influenced leading to the three main actor actions.

The fact that there is one policy network per policy arena is also an assumption that stems from the ACF and the concept of subsystems presented there. This is extended within this conceptualisation to simplify the approach. Each subsystem only contains actors that have a say in the issues being discussed and overall they form one policy network.

The assumption that specifies that the actors can only select one issue stems from the three streams theory. It is however enlarged to the entire model from common core to ACF. The reason behind this is to simplify the model and the number of actions that any actor can perform.

The conceptualisation assumes that the each of the actors has partial knowledge of other actors' beliefs. This approach is used to indirectly simulate bounded rationality. Because the influencing actions are performed based on the perception of the other actor's beliefs, the actors do not have full information of other actors. They can therefore not perform what would be the best action possible, they can only perform what they think is the best action possible. This results in flawed actions which can be argued to simulate bounded rationality. This is also linked to the assumption that actors gain knowledge of each other's beliefs through interaction. This is based on common sense but is also required to have a coherent model where actors progress in their knowledge of each other's beliefs.

The likelihood of performing an action is also based on common sense and modelling choices. It can be understood that actors are more likely to perform belief influencing actions on actors that they believe they can better influence. This approach is however changed in a subsequent version of this conceptualisation presented in Appendix A. After reflection, it was decided that it would make more sense that actors act on actors they are more likely to act on based on policy network criteria.

it was argued that the actors are more likely to perform actions on actors that they are more likely to interact with.

One of the biggest assumptions relates to the number of iterative stages that have been selected and what happens during these stages. The assumption is made that three stages are considered. These assumptions are based on a mix of modelling choices and literature. Overall, this approach resembles the policy cycle approach but using a simplified cycle. This choice is also made because of the need for a cyclical process to be able to ultimately simulate this conceptualisation.

Within this conceptualisation, it is assumed that external parties are the actors that transmit what happens within the world to the other actors present in the policy arena. This assumption is made based on the perception of the media in the literature (Cook et al., 1983; McCombs and Shaw, 1972). It is also used following common sense and as a modelling choices. It uses one type of actor to transmit crucial information. It also allows the modelling of issues such as the distortion of the reality by the media or even, in certain cases, lying by omission.

Finally, the last assumption that applies to the common core relates to the political affiliation and resources. This assumption is made mostly due to modelling choices. Resources are rarely mentioned in the literature. They are however necessary for actors to perform actions. Resources are therefore assumed to represent political and economic resources and are defined based on affiliation. An example would be that a party in power will have more support and therefore more resources. This example is flawed in some cases, think of the National Rifle Association in the United States for example. This approach could be modified in future versions of this work. It could also be entirely replaced by a concept of power. This is however not addressed in this report and considered to be beyond the scope.

Several assumptions are made specifically for the three streams model. There relate mostly to the streams approach. The use of a policy hierarchy aims at simulating the policy streams with the problem streams being approach through the belief hierarchy. Furthermore, it is important to let the actors choose between a policy and a problem as specified in the literature. The assumptions that actors can assemble in teams in directly taken from the policy entrepreneurship model (Mintrom and Vergari, 1996).

For the advocacy coalition frameworks, the assumptions relate mostly to the presence of coalitions. This is codified within the literature and this approach follows the literature's approach. The formalisation does provide additional details that are not present in the literature. This is shown in the next chapter. This is also the case for the assumptions made for the feedback effects.

For the diffusion theory, a set of assumptions are made. Most of these assumptions are taken to fit the literature while fitting within the common core approach. This leads to the need for a super-policy network and a subsystem network. Then the actions that are performed between the different actors in different subsystems are defined based on the actions that were already conceptualised in the common core and to fit with the five different links possibilities in the literature.

This justification approaches the conceptualisation from the assumption side. There is also an approach that can be taken from the concept side within the literature. The literature outlines a number of concepts, of which not all have been considered in the conceptualisation. This list of which concepts are considered and the reason why some are excluded is provided in Appendix G.

## 3.7. Validation

To ground the conceptualisation in the theories and to build confidence in the conceptualisation presented here, the conceptualisation was validated. The validation method used is a validation by experts. This method was found to be the most appropriate method to validate the work that was done to convert concepts and assumptions from the literature into agent based model concepts. Contact was established with several leading researchers in the field of policy making sciences, each specialising in one of the theories used in the model, as well as in efforts to use computer simulations for theoretical policy sciences analysis. A summary of the conceptualisation was sent to them before an one hour interview was organised. The researcher interviewed were: Professor Paul Cairney from the University of Stirling in the United Kingdom, Professor Nikolaos Zahariadis from the Rhodes College in Memphis, Tennessee, and Professor Christopher Weible from the University of Colorado Denver. Additionally, written feedback was also provided on the conceptualisation summary by Dr. Karin Ingold from the University of Bern in Switzerland.

The scope of the validation is not in any way to validate the policy making theories. As was mentioned earlier, the aim of this work is merely to use widely accepted policy making theories and attempt to appropriately translate them into modelling concepts that can be used in an agent based framework. The aim of the validation was therefore to establish a common understanding with these researchers in such a way that there understanding of specific details of these policy making theories were adequately considered for the model. The aim was also to press on aspects of the theories which are incoherent or which require considerably more detail to be used within a modelling framework.

### 3.7.1. Validation of the Approach

One of the topic addressed during the validation is the approach taken with the model. This is related to two main assumptions: it is possible to combine the different policy making theories and the policy cycle can be approximated as a 3-step process (agenda setting, policy formulation and world simulation) within the context of the present work.

As expected, there was pushback from each of the researchers on these two assumptions. Prof. Cairney argued strongly against the use of a policy cycle at all and noted that even Sabatier mentioned that the use of a policy cycle to explain policy emergence is hopeless. However, there was an understanding that for modelling, operationalisation purposes and specifically for an agent based model, reverting to a more linear approach of the policy cycle was required. Prof. Weible also argued about the use of this form of the policy cycle, no objections were raised on using only two steps: agenda setting and policy formulation.

Prof. Cairney also pushed back on the combination of the policy making theories. At the time of the interview, it was proposed that the model could combine the three streams theory approach for the agenda setting process and the advocacy coalition framework for the policy formulation process or vice versa. The reasoning behind such an approach was mainly that because some of the theories' concepts had been merged (consider the use of a belief tree within the three streams theory), this was technically feasible. Prof. Cairney argued that using both of these theories together within one model was ill advised as the two theories were contradictory as presented in the literature. Prof. Weible also noted that the combination of these two theories would disregard the difference in time scales that is inherently present in the two theories. In the literature, the ACF is considered to be a long term process with policy learning occurring over decades and coalitions that can last just as long. The three streams theory, on the other hand, works on a shorter time scale.

As a result from these discussions, some changes were performed on the approach taken for the model. The 3-step policy cycle approach was kept intact. Although there can be arguments made against the policy cycle approach, and with the fact that the policy emergence process is messy and non-linear, these descriptions are not constructive enough to provide details on alternative methods to approach the policy emergence process. This is especially striking as when using an agent based approach, there is a need for a structured approach to the system that needs to be modelled. Finally, it is important to note that, as Dr Ingold mentioned, Herweg et al. (2015) suggests that using the agenda setting and policy formulation fits well with a more formalised version of the three streams theory.

Changes were however made on the combination of the three streams theory with the advocacy coalition within one simulation. It was decided that it would make no sense to simulate both theories at the same time in different parts of the policy cycle. Although it is still technically possible to combine both theories, all experiments performed in the model will not combine both theories but will be constituted only of one theory at a time. This does not apply to the feedback and diffusion theories which can still be combined with both the three streams theory or the advocacy coalition framework.

### 3.7.2. Validation of the Three Streams Theory

The approach used for the three streams theory was mostly discussed with Prof. Zahariadis considering a lot of his research is related to this theory (Zahariadis, 2003; 2007; 2014).

Comments were targeted mostly at the concept of policy window and whether such a policy window would be observable within the three streams theory. This is also related to the selection of the problem and/or the policy by the actors present in the system. At the time of the interview, the three streams theory was using an approach where, during the agenda setting the actors would select a problem and during the policy formulation the actors would select a policy. However, and this was noted by Prof. Zahariadis, this is not how the policy window is described in the literature. The approach that was used only allowed for problem driven policy windows. It made it impossible for actors to first chose a policy and then proceed to the selection of a problem based on that policy.

Following this discussion, a considerable change was performed on the approach chosen for the three streams theory conceptualisation in the model. To better represent the policy window, it was decided that during both steps in the policy cycle, the actors would select a problem and a policy. They could decide to select first a policy or a problem based on their beliefs of what is currently most important. These changes were aimed at better representing the aspect of the policy window where actors choose a problem or a policy only considering their own beliefs.

Additional comments related to the three streams theory approach were linked to the transparency with which the modelling assumptions are made. Prof. Zahariadis insisted on the importance of reporting on all assumptions made as they can have a major impact on the behaviour obtained from the model.

Comments were also made on the approach considered for the introduction of external events in the model. The conceptualisation originally argued that external event (a crisis) would lead to a larger amount of resources for the actors in the system which have to deal with this crisis. Prof. Zahariadis argued the opposite, stating that an external event would lead to a constriction of the resources available to the actors. However, this should also be accompanied by a relaxing of the threshold that define consensus between the actors. The reduction of actions allowed, along with the larger threshold for the acceptance of a policy instrument, should then lead to the faster adoption of policy instruments to deal with the external event. The approach to the external event modelling was subsequently modified to fit with this approach.

### 3.7.3. Validation of the ACF

Feedback on the advocacy coalition framework was mostly discussed with Prof. Weible considering a lot of his research is related to this framework (Jenkins-Smith et al., 2014; Nohrstedt and Weible, 2010; Sabatier and Weible, 2014; Weible et al., 2009). The feedback provided on the ACF was mostly related to the importance of documenting the concepts that are transferred into a model. This effort would be useful to understand how many of the concepts are modelled so as to represent the messiness of the policy emergence process. A comment was also made on the term deep core belief that was used throughout the conceptualisation to represent the highest belief of the actors in the belief hierarchy. However, strictly related to the deep core definition that is provided in the literature, the belief level considered does not match with what a deep core belief is. The term was therefore changed to principle belief which illustrates a lower level of belief than deep core beliefs.

Overall the feedback obtained through this validation was positive and encouraging. Most of the conceptualisation was considered appropriate within the scope of the work performed here. Some elements had to be modified such as the approach of the three streams theory and the combination of the three streams theory and ACF within one policy cycle. However, this lead to a more coherent approach to the four policy making theories and should make the approach presented in this thesis more robust.

# 4

# The Formalisation

This chapter presents the formalisation of the policy emergence model. It follows the structure used for the conceptualisation. The common core is first formalised in Section 4.1. In this section details are provided on the subsystems, the agents, the belief hierarchy, the policy network, the agent actions and the cycle considered. Section 4.2 goes over the three streams related concepts such as the policy hierarchy, the teams and the cycle used for the three streams theory. Section 4.3 presents the formalisation of the ACF with the concepts of coalitions and the cycle used for the ACF. Section 4.4 looks into the formalisation of the feedback theory and Section 4.5 outlines the diffusion theory formalisation.

## 4.1. Common core

The common core is the centre part of the model which contains the concepts that can be placed in common for all policy making theories. The different parts of the common core are addressed here in the same order as they were addressed in the conceptualisation in Chapter 3.

### 4.1.1. The subsystems

The policy arena is designed as a subsystem in this formalisation. This term is borrowed from the advocacy coalition framework and represents the arena in which all the actors interact and influence on another. Each subsystem contains the different iterative stages: agenda setting, policy formulation and world.

### 4.1.2. The agents

The model is composed of five types of permanent agents and one temporary agent. These are divided in two main categories: the agents considered as they have to spend resources to perform actions and the agents that are passive as all the actions they perform happen regardless of resources or of the situation. One agent fits in both categories.

**Active agents** The active agents are the policy makers, the policy entrepreneurs and the external parties. Note that the external parties also have a passive role in which they provide the states from the truth agent, to the policy makers, the policy entrepreneurs and the electorate. This is considered to be a passive action as it is independent of resources.

The active agent's attributes are given as follows:

1. The *active agent* is represented as an 10-tuple given by `agent = (ID, subsystem, type, beliefHierarchy, affiliation, advocacy, resources, coalition, team, networkStrategy)` where `ID` is the unique ID of the agent, `subsystem` is the subsystem ID in which the agent is present, `type` is the choice of agent type, `beliefHierarchy` is the agent's personalised belief hierarchy, `affiliation` is the political entity the agent identifies with, `advocacy` is the list of the issues the agent is supporting, `resources` is the agent's resources (a relative value), `coalition` is the coalition ID to which the agent is a member of, and `team` is the team ID to which the agent is a member of, `networkStrategy` is the strategy that the agent will use for his/her networking actions.
2. A *type* corresponds to a choice of agent. This can either be a policy maker, a policy entrepreneur or an external party. Depending on the type of agent, the actions will change from one agent to another.
3. The *belief hierarchy* is made of two main parts: the agent's own belief hierarchy structure and associated values, and the belief hierarchies of all other agents and their values based on the agent's perceived knowledge of their beliefs (also referred as partial knowledge). The entire *belief hierarchy* structure is therefore a list of belief hierarchies which is as long as the number of agents present in the model. The details of the hierarchy structure itself are provided later on.
4. The *advocacy* is represented as a 4-tuple `(prob_as, pol_as, prob_pf, prob_as)` where `prob_pf` is the problem chosen by the agent during the agenda setting process, `pol_as` is the policy chosen by the agent during the agenda setting process, similarly `prob_pf` and `pol_pf` are the problem and policy selected by the agent during the policy formulation process. Note that some of these might not be used depending on the theories considered at any point. For the common core, only the problem is used.
5. The *resources* are represented as a decimal on the interval [0, 1]. Resources are distributed to the agents based on their affiliation and on that affiliation's representation within the model. These resources are used by the agent to perform actions on other agents. The resources are relative amongst all agents.
6. The *team* is represented as a 3-tuple given by `(team ID, belonging, strategy)` where `team ID` is the team to which the agent belongs, `belonging` is the agent's feeling of belonging in a team and `strategy` is the agent's strategy when wanting to create a new team. This attribute is only used in the three streams theory. The *belonging* value relates to how much the agent feel s/he is part of a team and defines the amount of resources the agent is willing to commit to his team. The *strategies* refers to the strategy selected by the modeller for an agent when it comes to the creation of a team.
7. The *coalition* is represented as a 2-tuple given by `(coalition ID, belonging)` where `coalition ID` is the coalition to which the agent belongs and `belonging` is the agent's feeling of belonging in the coalition.

**Passive agents** The passive agents are the truth agent and the electorate. Both types of agents only perform passive actions.

*The truth agent:* The truth agent is an agent not mentioned in the conceptualisation but required for the formalisation. This agent helps make the link between the world and the agents within the model. It gathers all the states of the world and provides them, as they are, to the external parties. One truth agent is present per subsystem. The only attribute of the truth agent is the belief hierarchy. This is a different one that for the active agents. It only contains the overall similar structure without any causal relations. Furthermore, it only contains the states for each of the issues.

*The electorate:* The electorate represents the different constituencies within a subsystem. There are as many electorate agents as there are political affiliations in the model per subsystem. The role of the electorate is to influence the policy makers in their aims. The following defines the attributes of the electorate.

The *electorate* can be given as a 6-tuple written as: `electorate = (ID, subsystem, affiliation, beliefHierarchy, representation)` where `ID` is the unique name of the electorate, `subsystem` considers in which subsystem it is, `affiliation` is its associated affiliation, `beliefHierarchy` is the associated belief hierarchy of the electorate and `representation` is the percentage of the total population which this electorate represents within the model. The sum of all *representation* from all electorates must always be equal to 100. The `representation` parameter affects the amount of resources received by the agents in the model. The belief hierarchy of the electorate is similar in structure to the one of the truth agent. It only contains the issues.

### 4.1.3. Belief hierarchy

The belief hierarchy is composed of two main parts: the issues and the causal relations. The issues are categorised in multiple layers: the deep core issues (the top layer), the policy core issues (the middle layers) and the secondary issues (the bottom layer). Secondary issues are linked to policy core issues through causal relations while policy core issues are linked to deep core beliefs through different causal relations. If multiple layers of policy core issues are present, each layer is also linked to each other with causal relations. The overall representation of this hierarchy structure is shown in Figure 4.1 for a three layered hierarchy.

Each issue is categorised by four parameters: the state, the aim, the preference and the awareness. The state defines the view of the agent of a certain issue as it is in the world. This view does not have to match reality and can be influenced by other agents. The aim shows what the agent would like to see happening in the world. The preference which is a derived parameter, defines the urgency that the agent places on the each issues. It is calculated depending on the state of the issue, the aim of the agent and the causal relations linked to this issue. The sum of all preference weights on any single layer of the belief hierarchy have to be equal to 1. Finally, the awareness represents the fact that agents are aware of a specific issue or not. It can take the value of 0 or 1. If an agent is not aware of an issue, it will not consider it in any calculation as if it did not exist. The belief hierarchy structure also contains causal relations. These link the issues on the different layers of the structure. These are the representation, in the agent's mind, of how each of the issues are related to each other within the technical model and which issues affect which other issue.

Each agent has an attribute called `beliefHierarchy`. This attributes contains two parts as mentioned previously: the agent's own belief hierarchy and the perceived hierarchies of all other agents in the model. It can be written as follows:

$$beliefHierarchy = [own_{hierarchy}, others_{hierarchy,n}] \tag{4.1}$$

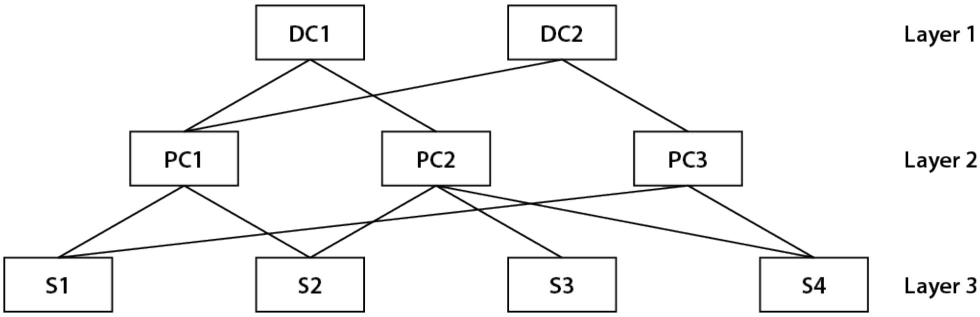


Figure 4.1: Example representation of a belief system with the three layers and several links between the layers. Not all possible causal relations are represented.

where $n$ represents the number of agents present in the model.

To further specify the hierarchy of the agent considered, the following can be said:

$$\begin{aligned} own_{hierarchy} &= [issues_k, causal\ relations_l] \\ issues &= [state, aim, preference, awareness] \end{aligned} \tag{4.2}$$

where $k$ defines the number of issues present in the belief hierarchy structure and $l$ the number of causal relations.

And it is also possible to specify the structure used to saved the perceived knowledge of the belief of the other agents:

$$\begin{aligned} other_{hierarchy} &= [issues_k, causal\ relations_l] \\ issues &= [state, aim] \end{aligned} \tag{4.3}$$

In both cases, the issues are specified with deep core issues first, policy cores following and ending with secondary issues. The causal relations are specified in the following example order: DC1-PC1, DC1-PC2, DC2-PC1, DC2-PC2, PC1-S1, PC1-S2, .... The state, preference and causal relation parameters are then specified on the interval of [-1, 1]. The preference is a percentage based parameters and is therefore calculated to be a number on the interval [0, 1].

#### 4.1.4. Policy network

The policy network is the network that links all agents within a subsystem. This network is composed of links with the following attributes:

1. A *policy network link* is represented as a 7-tuple `link = (agent1, agent2, awareness, awarenessDecay, conflictLevel)` where `agent1` and `agent2` are the agents at the end of a link, `awareness` is the awareness value, `awarenessDecay` is the decay value at which the awareness diminishes per time interval and `conflictLevel` is the conflict level characterising the relation between two agents for specific issues.
2. The *awareness* value can take three main values. The value -1 refers to the fact that both agents are not aware of each other's existence. They cannot network together without external introduction from a third party. For the value 0, the actors have no connection but know each other exist. They cannot network together until they have

raised their awareness level to a non-negative value through networking actions. Any positive integer relates the value of awareness between the two agents. The awareness is given on the interval $]0,1]$. Note that awareness is relative amongst all links. The policy network links between policy makers can never be -1 as policy makers are public figures. Furthermore, a link cannot be downgraded to -1, it can only start at -1. As the awareness decays over time at a specific rate, there are several actions or events that can lead to a growth or stop the decay in the awareness between two agents. This is detailed later on.

3. The *awareness decay* is represented by a 3-tuple `(value, time)` where `value` is the current value of the decay coefficient and `time` is a countdown. This countdown is by default set at 0, at which point decay of the awareness will happen. The countdown can be set at different values depending on actions that agents performed. The countdown will then go down to 0 every tick by 1. Whenever the countdown is not at 0, the decay is stopped.
4. The *conflict level* parameter is determined for each agent for each issue's aim and state and for causal relations. Note that the conflict level between two agents will be difference depending on which agents is considered as the conflict level is obtained based on the perception of another agent's beliefs. The conflict level is therefore given as a 2-tuple for each link: `(agent 1, agent 2)`. Then for each agent, the conflict level is defined per issue for the state and then for the aim, and all causal relations. The conflict level is then calculated using:

$$\begin{aligned} CW\ conflict\ level_{n,n_m} &= |CW_n - CW_{n_m}| \\ aim\ conflict\ level_{n,n_m} &= |A_n - A_{n_m}| \\ state\ conflict\ level_{n,n_m} &= |S_n - S_{n_m}| \end{aligned} \tag{4.4}$$

where $CW$ the causal weight, $A$ is the aim, $S$ is the state, $n$ is the agent for which the conflict level is calculated and $n_m$ is the perceived belief of agent $n$ on agent $m$ for that specific issue.
The resulting value is then formatted into a coefficient to be used in the grading of actions as is shown later on. When the result obtained is between 0 and 0.25, the conflict level is considered to be low, the coefficient is then set at 0.75. When the result obtained is between 0.25 and 1.75, the conflict level is considered to be medium, the coefficient is set to 0.85. Finally for a result higher than 1.75, the conflict level is considered high and the coefficient is set to 0.95. Note that both the intervals and the resulting coefficients can be varied by the modellers during experimentations to better tailor their model to their case studies.

**Network upkeep and maintenance** Each agent must maintain his/her policy network. For this, 20% of agent's resources can be used. The agents are allowed five actions, each time spending 4% of the total amount of resources for each action. The order in which agents are selected to perform their network actions is random. These numbers can be changed by the modellers for the purpose of theirs cases.

Two strategies are differentiated for these actions. The modellers have to specified which strategy each agent uses in the model inputs. They are given as follows:

1. Largest network strategy - the agent will look into increasing his/her network as much possible:
   (a) The agent first wants to keep all links active. Any link that is below 30% awareness level will be targeted for action. The lowest, but still above 0, will have priority.
   (b) If all links are above 30% awareness, the agent will look into introducing new links which had 0% awareness. The priority is placed on the link with agents with the closest beliefs.
   (c) If there are still resources left after step 1 and 2 are complete, the agent will maintain the links with the lowest awareness level in the network.
2. Focused network strategy - the agent will focus on maintaining a network of agents sharing its beliefs: (note that when it is stated similar belief, this relates to the problem that the agent is advocating for and no other issue)
   (a) The agent will look first for link where an agent with a similar belief (one of the agents has his belief within 0.2 of the other agent's aim belief) or higher belief level and with a awareness which is lower than 70%. The agent will prioritise based only on the awareness level as long as the belief criteria is met.
   (b) If no link qualifies, then the agent will seek to introduce new links in his/her network. The agent will select agents that have a similar belief or higher belief level.
   (c) If both step 1 and 2 are met, the agent will look into maintaining an awareness level above 70% for links still in service. The priority is put on the links with the lowest awareness value.
   (d) If all previous steps are met, then the agent will simply look for new links with the priority placed on agents sharing his/her beliefs.

The different actions mentioned above are performed as follows:

- An agent can increase the awareness in a network link if he feels the awareness level is too low. This awareness maintenance is dependent on three main parameters: the resources spent and the affiliation of both agents. The total increase in awareness for such an actions is calculated as:

  $$awareness := awareness + resources \cdot affiCoef_{Aff_n,Aff_m} \tag{4.5}$$

  where the $affiCoef_{Aff_n,Aff_m}$ is the weight related to the affiliation of the two agents. If they share the same affiliation, then it is equal to 1.
- Agents can also establish links with other agents for which they know they exist. This action can only be performed when the `link.awareness` parameter is equal to 0.
  If this is the case, then the awareness can be increased through the spending of resources. The new awareness level is then calculated similarly to the awareness maintenance but with a small malus to account for the initial investment costs. The equation is given as follows:

  $$awareness := resources \cdot affiCoef_{Aff_n,Aff_m} \cdot 0.5 \tag{4.6}$$

- The notion of similar belief is defined as agents being close for the aim on issues at the policy core level. There are several steps to seek agents with similar beliefs:
  1. Seek all links with awareness equal to 0 or higher and select their associated agents.

2. Select the aim parameter of the problem of the original agent.
3. For each associated agent, check its aim parameter for this same problem issue.
4. Calculate the difference of the parameter between the original agent and the associated agent for this issue.
5. Rank all differences from lowest to highest where the lowest is considered to be an agent of similar beliefs.

This ranking is calculated based on the agent's partial knowledge of other agent's beliefs.

### 4.1.5. Affiliation network

The affiliation network is a network that looks at the political affiliation of the different actors. Its links are represented as a 3-tuple given by `(affiliation1, affiliation2, affiCoef)` where `affiliation1` and `affiliation2` are the affiliations that are connected by the link and `affiCoef` represents the influence that an actor with an affiliation 1 can have on an actor with affiliation 2. The *affiliation coefficient* is given on the interval $[0,1]$.

### 4.1.6. The actions - Policy Makers

There is a set of actions that policy maker agents can perform within the model. These actions are individual framing where the causal relations are the target of the influencing action, aim influence where the issue aim is the target of the influencing acton and state influence where the issue state is the target of the influencing action. These three times of actions are presented below in more details.

When selecting an action, the agent will virtually influence all agents in his/her network. Based on this influence, s/he will calculate the new preference level for that agent. The agent will then go on to select the action that leads to the closest preference level. The equations used to calculate the influences in the beliefs are provided below. The simulation of the actions is based on the partial knowledge of the agent while the actual action will be performed based on the actual beliefs of the agents. This can lead to a mismatch between the expected results and the actual results.

**Individual framing** The agents can attempt to influence the causal relation belief of other agents. This is an individual framing action. For this action, all causal relations related to the issue selected by the agent are considered. The likelihood to perform such an action depends on several parameters which are outlined below:

$$CW_{n_m,temp} = CW_{n_m} + \left(CW_n - CW_{n_m}\right) \cdot resources \cdot awareness_{n,m} \tag{4.7}$$

where $G$ stands for the grade, $n$ is the influencing agent, $m$ is the influenced agent. $n_m$ is the perception of the beliefs of the influenced agent by the influencing agent and $CW$ is the causal weight of the causal relation

If this action is selected then the impact of the action on the beliefs of the influenced agents is given by:

$$CW_m := CW_m + (CW_n - CW_m) \cdot resources \cdot awareness_{n,m} \tag{4.8}$$

**Individual action - Aim change** The agents can also attempt to influence the aim beliefs on the different issues of the hierarchy of other agents. The likelihood that such action be performed is obtained in a similar way as shown below:

$$A_{n_m,temp} = A_{n_m} + \left(A_n - A_{n_m}\right) \cdot conflictLevel_{A,n,m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \cdot resources \tag{4.9}$$

The impact of such action is then calculated with:

$$A_m := A_m + (A_n - A_m) \cdot awareness_{n,m} \cdot resources \tag{4.10}$$

**Individual action - State change** Similarly to the influence on the aims of an agent, the states can also be influenced. The likelihood of such an action being performed is given as follows:

$$S_{n_m,temp} = S_{n_m} + \left(S_n - S_{n_m}\right) \cdot conflictLevel_{S,n,m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \cdot resources \tag{4.11}$$

And the impact is calculated as follows:

$$S_m := S_m + (S_n - S_m) \cdot awareness_{n,m} \cdot resources \tag{4.12}$$

### 4.1.7. Preference calculation (issues)

As mentioned earlier on, the policy maker has a limited attention span. This results in having to select one issue at a time for which s/he thinks is the most urgent issue. This urgency is defined as the preference of an agent and is calculated for each layer in the belief hierarchy of the policy maker. Two cases must be distinguished for calculating this urgency: whether the layer considered is at the top or in the rest of the hierarchy. The preference is calculated for each issue and the sum of all preferences on each layer must be equal to 1.

**Preference calculation for the principle beliefs** For the top layer which is composed of the principle beliefs, the preference is calculated differently than for the other layers. This is because these beliefs are on the highest layer and can therefore not be connected to higher layers with causal relations. The calculation of the preference for each issue is given by:

$$P_i = \frac{|A_i - S_i|}{\sum_{j=1}^{n} |A_j - S_j|} \tag{4.13}$$

where $j$ is defined at the number of principle belief issues and $i$ characterises the principle belief issue being selected for the calculation.

**Preference calculation for the policy core and secondary beliefs** The preference calculation for the other layers in the belief hierarchy is adapted to include the causal relations that link these layers to higher up layers. This calculation applies to the policy core beliefs which are in the middle of the hierarchy and the secondary beliefs at the bottom.

To calculate the preference, the gap between aim and state for the issues is considered along with the impact of the causal relation on the gap of the issue on the above layers.

The causal relations are not always helping bridge the gap between the aim and the state of issues on a higher layer. If this is the case, then the causal relations are not considered within the calculation as there effort is counter productive within the mind of the agent. The resulting equation that can be used to calculate the preference for these layers is given by:

$$P_k = \frac{|A_k - S_k| + \sum_{j=1}^{n} |CW_j \left(A_j - S_j\right)|}{\sum_{l=1}^{p} \left[|A_l - S_l| + \sum_{j=1}^{n} \left|CW_{j,l} \left(A_{j,l} - S_{j,l}\right)\right|\right]} \tag{4.14}$$

The sums only include these terms if $CW_j$ and $\left(A_j - S_j\right)$ have the same sign. If it is not the case, these terms are not considered. And where $p$ is defined at the number of policy core issues, $k$ characterises the policy core issue being selected for the calculation, $j$ specifies the associated deep core and $CW$ represents the weight of the causal relation.

Based on these preferences obtained, the agent will select one issue to advocate for as mentioned earlier. For each layer, the agent will choose the issue with the highest preference. This is the case for each layer. The actions that the agent will then perform will be to influence other agents on the issue they have selected specifically.

### 4.1.8. Partial knowledge and awareness decay

The likelihood of performing an action is based almost entirely on the perception of an agent on another agent's beliefs. This is also referred as the partial knowledge of an agent. This partial knowledge is the representation that agents have of other agent's beliefs. To perform better informed decisions, the agents must update their partial knowledge about other agents.

This update is performed after two agents have interacted with one another. When an action is performed, both agents have come into contact and have learnt about each other's beliefs on the issue they have interacted on. This allows them to gain knowledge about the other's belief. Therefore, for each action implemented, each agent will have access to the belief of the other agent concerning the issue influenced during the action. This access is not complete, the agents will gain the beliefs of the other agent with a small uncertainty amount.

Furthermore, because the two agents have interacted, their awareness of one another will not decline. It is therefore kept at the current level for several time steps. Only after these time steps have passed and if both agents have not interacted since, the decay of their awareness of one another will continue.

### 4.1.9. Agenda and agenda selection

The *agenda* is a `l`-tuple given by `agenda = (issue, problem, policy)` where `issue` is the issue that is placed on the agenda by the policy makers, `problem` is the problem selected and `policy` is the policy selected by the policy makers. Note that the problem and policy attributes are only considered within the three streams theory, they are left empty within the common core.

To constitute the agenda, an issue has to be chosen for the entire subsystem. For this two methods are proposed which can yield different results. The first method considers all the top issues as graded by the policy makers. They are affected by their normalised resources. The grade of each issue is the sum of all agent's resources which have chosen that issue as their preferred issue. Whichever issue has the highest grade becomes the issue on the agenda.

The second method used for the ranking and selection of the issues is similar to the first one. The difference is that here all issues are taken from each policy maker. They are then weighed all together (and not simply the issues at the top of the ranking of each agent). This approach is meant to represent a different approach to the power dynamics in the model. The grade for each policy is then obtained as:

$$rankingGrade = \sum_{i=0}^{n} \left( \frac{1}{P_{rank}} \cdot resources_n \right) \tag{4.15}$$

where $n$ is the number of agents and $P_{rank}$ is the ranking of the policy for that agent.

The issue with the highest grade is then taken as the issue for the agenda.

### 4.1.10. The actions - Policy entrepreneurs

The actions of the policy entrepreneurs are the same as the ones presented for the policy makers. The only difference is that the policy entrepreneurs cannot choose the agenda.

### 4.1.11. The actions - External parties

As mentioned in the conceptualisation, the have a more complex roles that the policy makers and entrepreneurs. They have different and similar actions to these actors. Their first role is to transmit the states of the world to the different agents in the model. This role is passive and does not require any resources. The second and third roles that the external parties can perform are active roles. They perform actions on different agents which means that they require resources. The second role, blanket framing, is attributed 50% of the total resources of the external party while the third role, blanket influence on the electorate, is attributed the last 50% of the resources. These resources are then spent in intervals of 10% of the total amount of resources on each of the actions. These resources values can be affected by the modeller decisions.

**Transmitting the states** The states of the issue in the hierarchy beliefs of all agents are updated based on the information they get from the external parties. These external parties have access to the full and real states of the world. They can obtain these states from the truth agent which has the complete set of the states for each issue directly from the world. Each external party selects states that s/he finds interesting to transmit them to other active agents. This transmission of the states can be affected by the political affiliation of the agents as agents of different affiliation are unlikely to fully trust one another. The equation used to calculate this update of the states is given below:

$$S_{agent} := S_{agent} + \frac{1}{n} \sum_{i=1}^{n} \left( \left( S_{EP_n} - S_{agent} \right) \cdot affiCoef_{Aff_n, Aff_m} \right) \tag{4.16}$$

where $S$ stands for the issue state, $n$ is the number of external parties, $EP$ stands for external parties and $affiCoef_{Aff_n,Aff_m}$ is the affiliation related weight. The affiliation coefficient is the one that relates the affiliation of the agent and the affiliation of the external party selected. If an external party has not selected that specific state, then s/he will not be able to provide the state for that issue. Furthermore, the external parties will only transmit the states to agents within their network. This can lead to some agents lacking states for specific issues because of the composition of their policy network.

**Blanket framing** The external parties can also attempt to influence the understanding of the world of other external parties, the policy makers and policy entrepreneurs. The external parties perform such influence on all agents at the same time which leads to this action being called blanket framing. The external parties virtually influence all agents and calculate the new beliefs. They then select the action that will have the largest impact on all of the actors to be implemented. Such action can only happen on the agents that are within the policy network of the external party. All causal relations related to the issue selected by the external party can be influenced.

The likelihood of performing a blanket framing action is calculated as follows:

$$\begin{aligned} G_{CW,n_m} &= \left(CW_n - CW_{n_m}\right) \cdot affiCoef_{Aff_n,Aff_m} \cdot resources \cdot \frac{1}{nagents} \cdot actionWeight_{n,m} \\ G_{CW,n} &= \sum_{m=1}^{nagents-1} G_{CW,n_m} \end{aligned} \tag{4.17}$$

where $CW$ is the causal weight selected, $n$ the external party performing the framing, $m$ the affected agents considered and $nagents$ the total number of agents.

The action on a causal relation for which the grade is the highest is then selected to be implemented. The causal relation of the affected agents are then given by the following equation:

$$CW_m := CW_m + (CW_n - CW_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \tag{4.18}$$

**Electorate influence** Finally, the external parties can influence the goals of the electorate. This is done following the same template the goal influence of the policy makers and entrepreneurs. The only difference is that it is once again blanket influence which means that all electorate agents are affected at once. Note that because the external parties have a limited attention span, they can only influence the electorates on the issue they have selected. The impact of this influence is given by the following equation:

$$A_{El,i} := A_{El,i} + \left(A_{n,i} - A_{El,i}\right) \cdot affiCoef_n \cdot resources \cdot \frac{1}{nEl} \tag{4.19}$$

where $n$ is the external party, $i$ is the issue and $nEl$ is the number of electorates.

### 4.1.12. Electorate passive action on policy makers

The policy makers are passively influenced by the electorate. Each electorate has a certain affiliation to which policy makers are also related. Each policy makers' issue aim will be influenced by their respective electorate. This happens as a passive effect where the issue aims of the policy makers slowly progress towards the issue aims of the electorate. The equation to calculate the change in the aim of the policy maker is given as follows:

$$A_{PM} := A_{PM} + (A_{El} - A_{PM}) \cdot 0.001 \cdot |A_{El} - S_{El}| \tag{4.20}$$

where $El$ stands for electorate and $PM$ for policy maker. Note that this is only performed for the issues of the policy maker for agents with matching affiliations. Furthermore, the value 0.001 is arbitrary and can be changed by the modeller depending on the case study.

### 4.1.13. Policy instruments

The policy instruments are measures that can are chosen by the policy makers to impact the real world. Policy entrepreneurs and external parties can also influence the policy makers in their choices. To assess the different policy instruments, the different active agents assess the impact of these instruments on the secondary issues in their belief hierarchy. These instruments have an impact on the gap between the states and the aim of each of these issues. The policy instruments can be described as follows:

1. A *policy instrument* is represented as a 7-tuple `(name, impact, change, layer, children, awareness, feedback)` where `impact` is related to the impact of the policy on a specific issue, `change` is the objective change expected in the world due to this policy, `layer` corresponds to the layer in the instrument hierarchy (when used), `children` corresponds to the instruments linked to the selected instrument in the instrument hierarchy, `awareness` is related to the availability of the policy for a specific agent and `feedback` is related to the expected model feedback from the implementation of the policy considered.
2. The *impact* of a policy instrument is given as a 2-tuple: `(issue, impact)` where `issue` defines which of the secondary issues is affected and `impact` specifies by how much.
3. The *change* due to a policy instrument is the subjective representation of the impact of the policy instrument. These are the actual changes that will occur in the world with the implementation of the instrument. They are defined by the modeller and are fully independent on the agents.
4. The `layer` and the `children` are both parameters that related to the three streams theory. They are therefore outlined in that section and are left empty for the common core.
5. The *awareness* parameter defines whether a certain policy instrument is known in a specific subsystem. This parameter is related to the diffusion theory and is further outlined in the section dealing with the diffusion theory.
6. The *feedback* parameter contains the feedback effects as defined by the modeller. This parameter is related to the feedback theory and is further explained in the feedback theory section.

### 4.1.14. Preference calculation (instruments)

Similarly to the agenda setting round, in the policy formulation round, the agents have a limited attention span. They can therefore only select one policy instrument at a time. The calculations used to select these instruments are slightly different than the ones in the agenda setting. They are shown below

**Preference calculation** The preference calculation of the secondary issues within the context of a policy formulation iterative stages are tweaked from the calculation presented in the agenda setting round. The main reason is that for the policy formulation, the number of issues considered is narrowed down by what is on the agenda. The agents can therefore only consider issues in the secondary belief layer that have a direct effect, according to their beliefs, on the issue that is on the agenda. All other issues are not included within the preference calculation. For the rest, Equation 4.14 is still used to calculate the preferences of the different issues for each agent according to their own beliefs.

**Instrument selection calculation** Once the preferences for the different secondary issues have been attributed, it is possible to look at the preference of the instruments. These are used by the agents to assess the instruments and select the one they find most important. The equation that is used to calculate the preference of the different instruments is provided below. Similarly to the calculation of the preferences in the belief hierarchy, only instruments with impacts that have the same sign as the belief gap (aim minus state for a specific issue) are considered. The other instruments are counter productive and are therefore directly excluded from considerations.

$$P_i = \sum_{j=1}^{n} \left[ impact_j \cdot \left( A_j - S_j \right) \cdot P_j \right] \tag{4.21}$$

where $n$ is the number of impacts this policy instrument has, and $j$ represents the secondary issue and the associated impact of the policy instrument on that issue.

Once all the preferences have been calculated, the agent will select the instrument with the highest preference. This will help define the actions that each agent can perform. Because no actions can be performed on the instruments directly, the agent will be able to perform actions on all issues directly related to the instrument and all causal relations which link the issue on the agenda and the issues related to this instrument. The likelihood and the impact of the actions are calculated in the same way as was shown previously. The aim here for the agents is to convince other agents that the instrument's impact is as high as they perceive because their causal relations, aims and states beliefs are similar.

### 4.1.15. Policy instrument selection and implementation

Similarly to the agenda setting round, the policy makers are the agents that can selected a policy instrument. Additionally, they will decide if a policy instrument should be implemented. This is done through one of two strategies which can be chosen by the modeller and which rare presented below.

**Unanimity** If unanimity is required, all policy makers must have selected the same policy instrument for it to be implemented. If this is not the case, the instrument will not be implemented and the round will close without a definitive output.

**Majority** If a majority is required, 50% plus one policy maker must select the policy instrument for it to be implemented. The resources of the different policy maker has no impact on this majority as it had in the agenda setting round. If a majority cannot be found, the policy instrument will not be implemented.

### 4.1.16. External events

The external events that are considered are external events that affect the agents. External events that would affect the world such as a flood for a hydrological model are of no interest and considered out of scope of this report. However, the impact on the model such as a change in the electorate composition due to the flooding is of interest.

The following is a non-exhaustive list of potential external events which the modeller could use.

1. An election - this would create a change in the electorate representation parameter which would in turn lead to different resources allocation for the policy makers.
2. The introduction of a new issue - a new issue could be introduced to the system or to a subsystem. This would affect the knowledge parameter for an issue for all agents present in the model.
3. Resources shift - a shift in the resources distribution due to an external event could be modelled. The way the resources are attributed could be modified to simulate a crisis situation were resources are scarce. This could also be modelled as a reduction in the possibility of actions (increasing the amount of resources that is spent per action). parameter would be changed.
4. Policy network shifts - change in the awareness parameter of specific network links.
5. Affiliation network shift - change in the affiliation coefficient parameter that defines the interaction possibilities between two different political affiliations

### 4.1.17. The model cycle

For this formalisation, it is assumed that the different iterative stages are performed consecutively. First the agenda setting iterative stages are performed, then the policy formulation iterative stages and finally the real world. A further assumption is to assume that there is only one round of each of these steps is performed. This leads to a 3-step model with an agenda setting step, a policy formulation step and a world simulation step. The agenda which is obtained at the end of the agenda setting helps defines what the agents will be interacting about within the policy formulation.

This has several consequences. The first one is that the beliefs hierarchy of the agents must be a three-layer hierarchy. At the top are the principle beliefs, then in the middle the policy core beliefs and at the bottom the secondary beliefs. Within the agenda setting, the agenda decide on an agenda issue from the second layer, the policy core issues. Within the policy formulation, the agents select instruments which are related to the third layer.

The steps used to mode this approach are then detailed as follows:

1. World round:
    (a) *World simulation:* The world which is an exogenous party to the model or an internal technical model are run to provide inputs for the next step.
    (b) *Trigger of external events:* Any event that the modeller decides to implement are activated at this stage of the model cycle.
    (c) *Update of the truth agent:* The technical output is converted into normalised data fitting with the issues present in the belief tree. These are placed in the truth agent's $S$ parameters.
    (d) *Electorate action on policy makers*
    (e) *Transmission of the states:* The external parties select their states of interest from the truth agent and pass the information to the agents within their policy net-

work.

2. Agenda setting round:
   (a) *Preference calculation (issues):* Each agent calculates the preference for their principle and policy core beliefs. The agents then each select an issue that s/he will advocate for in his/her policy core beliefs based on the preferences calculated.
   (b) *Agent interactions:*
      i. *Resources received:* Each active agent receives its resources based on his/her political affiliation.
      ii. *Network upkeep or maintenance*
      iii. *Belief influence actions:* All active agents perform their respective actions. The order in which the agents perform their actions is made random to not favour agents with first or last actions.
   (c) *Preference calculation (issues):* Each policy maker updates his preferences for his principle and policy core beliefs. This update of the preference is necessary to take into account the changes that might have occurred as a results of the agent interactions. Each policy makers choose the issue with the highest preference as their issue of preference.
   (d) *Agenda selection*
3. Policy formulation round:
   (a) *Preference calculation (instruments):* Each agent update his preference for his secondary beliefs based on the issue on the agenda. Each agent then selects a policy instrument that s/he will be advocating for.
   (b) *Agent interactions:*
      i. *Resources received*
      ii. *Network upkeep or maintenance*
      iii. *Belief influence actions*
   (c) *Preference calculation (instruments):* Each policy maker upgrades their policy instrument preferences after the interaction step.
   (d) *Policy instrument implementation*
4. *The model advances:* The clock is advanced to the next tick. Programming of ticks actions are also performed (data collection, policy network awareness decay, ...).

## 4.2. Three streams theory

The three streams theory introduces a number of changes and additional concepts to the common core. These are detailed here. The first important addition and change is related to the policy instruments which are now assembled in an instrument hierarchy. Another change comes with the fact that the agent now must choose between a policy and a problem based on the calculated preference. Furthermore, because agents are not able to select policies, they are provided with an additional action. Finally, the agents can assemble in teams. This requires an algorithm for the creation of such teams and it brings in more actions that the actions can perform within and outside of their teams.

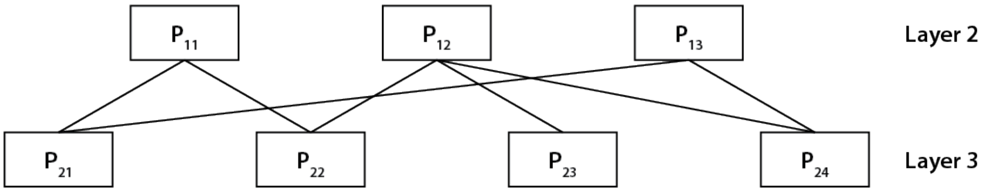


Figure 4.2: Instrument hierarchy representation with the two layers.

### 4.2.1. The policy instruments

As explained in the conceptualisation, the actors now each have an instrument hierarchy similar to their belief hierarchy. To formalise this hierarchy, two attribute within the policy instruments are activated. These are the layer and children attributes. The layer attribute defines in which layer of the hierarchy the instrument fits. These layers are related to the layers present in the belief hierarch. This means that policy instruments in the second layer of the instrument hierarchy will have an impact on the issues which are in the second layer of the belief hierarchy. The children attributes helps understand which instruments are related across the different layers. This is defined by the modeller and is useful to navigate from one round to another. When a certain instrument is placed on the agenda from the second layer, then only his children present in the third layer can be considered by the agents. All other instruments are considered irrelevant. A representation of the instrument hierarchy is given in Figure 4.2.

There is an additional change that occurs within the policy instruments. The impact is not objective anymore. The impact is now a subjective parameters very much like the states and aims for the issues in the belief hierarchy. This is important as the agents will be able to influence other agents on their beliefs of the impact of the different instrument available to them.

### 4.2.2. Preference calculation (problems and policies)

As mentioned within the conceptualisation, the agents can now select a policy or a problem. For that they must grade all problems and policies in every layer. They can then select the policy or problem that has the highest grade.

**Problem and policy preference calculation** The problems and policy grades are obtained differently. The problems are based in the belief hierarchy and their grades are calculated similarly to the issues in the common core. The equation is given as:

$$G_{prob,i} = (A_i - S_i) + \sum_{j=1}^{n} \left| CW_j \left( A_j - S_j \right) \right| \tag{4.22}$$

where $i$ corresponds to the policy core considered and $j$ the related deep core issues.

The policy instrument are assessed on their impact on the different gaps in their associated issues in the belief hierarchy. The equation used to calculate their grades is given by:

$$G_{policy,i} = \sum_{i=1} (A_i - S_i \cdot I_i) \tag{4.23}$$

where $i$ corresponds to the policy core affect by the policy selected and $I$ is the impact expected from the policy.

Once all possible policies and problems have been graded, the agent will select the one with the highest grade. Then the process is repeated again but for the associated issues. This is done with only problems related to the policy selected if a policy was selected first or with the policies related to the problem selected if the problem was selected first.

The actions that the agents will perform will be based on whether they first selected a problem or a policy. These actions are detailed in a subsequent section.

**Agenda and agenda selection** Within the three streams approach, the agenda selection is a little different than for the common core. The agenda is now composed of two parts: a problem and a policy. The issue attribute of the agenda is left empty. The rest is similar to the common. The problem selected for the agenda is the most popular problem for all agents considering their respective resources while the policy chosen is the most popular policy amongst all agents also considering their resources.

**Policy instrument selection and implementation** For the policy formulation round, the procedure to select and implement a policy instrument is similar to the common core procedure. The policy chosen by all policy makers is considered. If a policy is beyond the threshold set but the modeller for implementation, the policy will be implemented. The problem chosen by the policy makers is not taken into account.

### 4.2.3. The actions (active agents)

The influencing actions that the agents can perform are mostly similar to the ones in the common core. The main difference is that all their actions are performed on the problems if they have first selected a problem. The policy makers and entrepreneurs can perform framing, state influence and aim influence actions on other agents based on the problem they have selected in their belief hierarchy. The external parties can perform their blanket framing on other agents and blanket aim influence on the electorate. This is also based on the problem they have each selected.

For the agents that have selected a policy, an additional action is added. This action is an action that influences the impact beliefs of the policy instrument selected by the agent. For all agent, this action replaces the framing or blanket framing action. The aim and state influence actions remain the same. Similarly to the other actions, the agent assess what impact his/her action will have on the preference of the other agents and decides on the action to select based on that result.

The likelihood of performing a policy action is given as follows:

$$I_{n_m,temp} = I_{n_m} + \left(I_n - I_{n_m}\right) \cdot resources \cdot awareness_{n,m} \tag{4.24}$$

where $n$ is the agent performing the action, $m$ is the agent on which the action is performed, $I$ stands for the impact that the action has on the mentioned issue. Note that if the instrument has an impact on four separate issues, then the agent will assess the likelihood of influencing each of the four impacts contained in that policy instrument.

The impact of the action is then given as follows:

$$I_m := I_m + (I_n - I_m) \cdot resources \cdot awareness_{n,m} \tag{4.25}$$

where $n$ is the agent performing the action, $m$ is the agent on which the action is performed.

### 4.2.4. The teams

As mentioned in the conceptualisation, the three streams theory includes the concept of teams. This concept is formalised within this section. Teams contain a number of agents that feel they share their beliefs for a specific issue. A team is therefore given as a 6-tuple written as: `(team ID, lead, members, issue, creation, resources)` where `lead` is the leader of the team (the agent that created the team), `members` is the list of members that are part of the team, `issue` is the policy issue that the team is advocating for (policy or problem), `creation` is the time at which the team has been created and `resources` consists of the resources at the disposal of the team to perform actions. The resources are calculated as the sum of all the members belonging level.

**Agent-team actions** The agent-team actions are all actions that each agent performs to either decide to join or create a team. It also consists of actions related to the disbanding of teams and the checking that the team requirements are still met. Each agent goes through all of these actions each tick. Each agent can only be part of one team at a time in the agenda setting process and one team in the policy formulation process. Note that all actives agents can be part of teams. The following list presents the different actions that are taken in chronological order in which they are performed in the model: start a team, join a team, leave a team, disband a team and calculate belonging level.

**Start a team** An agent that wants to start a team has to consider different requirements. Two different cases have to be considered here: the case where the agent first chose a problem and the case where the agent first chose a policy.

If the agent first chose a problem then the first requirement is that for the secondary issue chosen, the gap between aim and state must be above a certain threshold. This threshold is 0.8 in general but can be set to 0.5 in cases where a change in the magnitude of the state from the previous tick is larger than 0.5 (in case of an external event). This must be the case for all agents if they want to join the team. The second requirement relates to the belief states. For the agenda setting, it is the causal relation between the deep core issue with the highest preference for the starting agent and the policy core issue selected as the problem. For the policy formulation, the causal relation selected is the one relating the problem on the agenda and the secondary issue selected as the problem by the agent. All agents that want to join the team must be within 0.5 of the value of the causal relation for the agent starting the team.

If the agent first choses a policy, then there is a small change in the requirements looked at. The agent still looks at the gap requirement. However the second requirement is now dependent on the impact that the policy has on the secondary issues selected as the problem by the agent that is starting the team. The impact on the associated problem should be within 0.5 for the other agents considered to enter the team.

If both of these requirements are met, then the agents qualifies to join the team. Note that for each agent contacted, the agent starting the team loses 2% of his resources and the contacted agent loses 1% of his resources. This is to justify the resources needed for the exchange of knowledge. Furthermore, the agent starting the team will initially assess the other agents based on his knowledge of their beliefs. This leads to the spending of resources. If his perception of the other agent's beliefs are not true, then the agent will not join the team but the resources will have been spent regardless. The resources are also used to gain some information on the beliefs of the other agents. Even though the other agents might not be interested, spending these resources allow the agent to gain knowledge of the beliefs of the other agent within a certain range. Through this exchange of knowledge the agent also provides his own beliefs to the agent being contacted.

The creation of the team requirements are then based on the strategy that the agent is using. Two strategies are considered. The first strategy consists of starting a team with all the agents found that meet the requirements mentioned earlier. The team will then be composed of the maximum number of agents possible. The second strategy consists of starting a team once a certain number of agents has been established to meet the aforementioned requirement.

Upon the creation of a team, all agents that are part of the team are added to the member list. The lead agent of the team is the agent that started the team. Each agent's belonging level is also calculated based on a weighted average of the beliefs of the team on the state of the issue advocated for. Joining a team will also lead to the half of the awareness decay in the links between the agents present in the team, effectively counting as an action.

**Join a team** An agent can join a team if s/he is not already part of a team. For this, the agent will check the same requirements as when creating a team (gap and causal relation/impact requirements). This is done for the issue of the team s/he is approaching. For each team that the agent probes, 2% of his resources are spent. If the requirements are met, then the agent will join the team and be added as a member of the team. The agent is allowed to spend 50% of his resources for such a search. Once these resources have been depleted or all team have been considered, the agent moves on.

**Leave a team** An agent can leave another team for one reason: because his belonging level is too low. The belonging parameter of the agent is checked every time period. If it descends below 30% then the agent will automatically leave the team. If the team remaining has less than three agents, it will be disbanded right away. Note that the belonging parameter is updated based on the perception of an agent on another agent's beliefs (partial belief) without full knowledge. This will artificially increase the life of teams.

**Disband a team** As mentioned earlier, a team will be disbanded if the problem or policy advocated by the team does not match the problem or policy advocated by the lead agent. This can be due to the leader being influenced and having changed his/her preferences. This is checked every five time periods. The second reason for which a team will be disbanded is if the agents present in the team to not meet the team creation requirements anymore. This is also checked every five time periods.

**Belonging level setting** The belonging level in a team is used to measure how much resources an agent is willing to contribute to the team resources and how much s/he will keep for his own individual belief influence actions. This belonging level is entirely related to the problem or the policy being advocated by the team.

The belonging level is obtained differently depending on whether the team has selected an problem or a policy. For a problem, the belonging level is obtained through the problem that is being advocated by the entire team. The steps are shown below:

1. The weighted average of all agent's belief on the state of the problem being advocated by the team of all agent is calculated using:

$$S_{prob,weighted} = \sum_{i=1}^{n} resources_n \cdot S_n \tag{4.26}$$

   Note that this weighted average might be difference for each agent as it is based on partial knowledge and not full knowledge. The belonging parameter will be affected by the perception of other agent's beliefs.
2. The belonging level is then calculated using the following equation:

$$Belonging = 1 - \left|S_{prob,agent} - S_{prob,weighted}\right| \tag{4.27}$$

The belonging level in a team that is advocating for a policy is different. It is calculated using the impacts that the policy has on the different issues in the belief hierarchy. The belonging level of each agent is calculated as the difference between his/her own total belief and the average of the other agent's total beliefs. The 'total belief' of each agent is calculated for the policy that is being advocated by the team according to the agent's own beliefs as the sum sum of the absolute value of all impact that policy has. To estimate the total belief of other agents, agents have to rely on their partial knowledge. The steps are provided below:

1. The total belief of all agents is calculated:

$$TB_{pol,m} = \sum_{i=1}^{p} |I_{n_m,issue}| \tag{4.28}$$

   where $m$ is the agent being considered, $n$ the agent performing the estimation of the total belief and $p$ the number of impacts that the policy instrument has.
2. The average of the other agent's total belief is calculated:

$$TB_{pol,avg} = \sum_{i=1}^{p} |TB_{pol,m}| \tag{4.29}$$

3. The belonging level is then calculated using the following equation:

$$Belonging = 1 - \left|TB_{pol,m} - TB_{pol,avg}\right| \tag{4.30}$$

**Team belief actions** Once the teams have been constituted, these teams must perform actions. These are the belief actions. There are two types of actions that the team can conduct. They can first perform intra-team actions to help the team get more consistent beliefs. They can also perform inter-team actions. In this case the aim is to convince other agents outside of the team that the belief of the team are more important. Each type of actions uses 50% of the resources reserved for the team. These actions are performed in intervals of 10% of the total amount of resources reserved. The resources available to team are equal to the sum of the belonging attributes for each of the members of the team.

- Intra-team actions:
  There are four main intra-team actions: blanket framing on causal relations, blanket framing on policy instrument impact, direct influence on aim and direct influence on state beliefs. The aim for these actions is to help the entire team be a more coherent entity with agents having similar beliefs regarding the issues they advocate for. As each of the team is based on awareness between the different agents, each agent has a say on which action should be chosen. Therefore each agent assesses all of the possible actions based on the partial knowledge he has of the other agents in the team. Because the agents are in a team, they all know fairly well the beliefs of the others in the team.
  Within the context of a team, these actions are performed by the team leader. Considering that the agents are all in the same team, they all know each other's almost exact beliefs and it therefore does not matter who decides on which action to take as the results will be the same.
  The blanket framing action on causal relation is used in the case where the team has selected a problem as the issue it is advocating for. The grade and impact of the actions are the same as the ones presented in Equation 4.31 and Equation 4.18 respectively.
  The blanket framing action on the policy impact is used in the case where the team has selected a policy as their issue. The grade attributed for performing such action is calculated as follows:

$$\begin{aligned} G_{I,n_m} &= \left(I_n - I_{n_m}\right) \cdot affiCoef_{Aff_n,Aff_m} \cdot resources \cdot \frac{1}{nagents} \cdot actionWeight_{n,m} \\ G_{I,n} &= \sum_{m=1}^{nagents-1} G_{I,n_m} \end{aligned} \tag{4.31}$$

  where $I$ is the impact selected, $n$ the agent considering the action, $m$ the affected agents considered and $nagents$ the total number of agents in the team.
  The blanket framing action on the problem is used in the case where the team has selected a problem as their issue. The likelihood of performing this action on the states is given by the following equation:

$$\begin{aligned} G_{S,n_m} &= \left(S_n - S_{n_m}\right) \cdot affiCoef_{Aff_n,Aff_m} \cdot resources \cdot \frac{1}{nagents} \cdot actionWeight_{n,m} \\ G_{S,n} &= \sum_{m=1}^{nagents-1} G_{S,n_m} \end{aligned} \tag{4.32}$$

  The likelihood for the influence of the aims of the problem is calculated the same way but through substitution of the conflict level from the states to the conflict level of the aims.
  For each of these actions, the grade is the sum for all agents of the action. The total grades for each action is compared and the action with the highest impact is selected to be implemented.

The impact of all these actions is then given, in order, as:

$$
\begin{aligned}
CW_m &:= CW_m + (CW_n - CW_m) \cdot resources \cdot affiCoef_{Aff_n, Aff_m} \cdot \frac{1}{nagents} \\
I_m &:= I_m + (I_n - I_m) \cdot resources \cdot affiCoef_{Aff_n, Aff_m} \cdot \frac{1}{nagents} \\
S_m &:= S_m + (S_n - S_m) \cdot resources \cdot affiCoef_{Aff_n, Aff_m} \cdot \frac{1}{nagents} \\
A_m &:= A_m + (A_n - A_m) \cdot resources \cdot affiCoef_{Aff_n, Aff_m} \cdot \frac{1}{nagents}
\end{aligned}
\tag{4.33}
$$

- Inter-team actions
  There are also four inter-team actions: framing on causal relations, framing on policy impact, direct influence on aim and direct influence on state beliefs. The aim for these action is to influence the belief of individual agents present outside of the team. These actions are graded by each of the agents present in the team and the action that has the most merit from all actions of all the agents is the one selected by the team as a whole. To benefit better from the team, the agents can count on the overall team policy network and the team resources. The framing on causal relation is performed if the team has chosen a problem as its issue while the framing on policy impact is for when the team has chosen a policy as its issue.
  To better benefit from the team network, a shadow network is established between the team and all agents outside of the team. The awareness for the established links is equal to the highest awareness found between one of the agents in the team and the outsider agent. Furthermore, the conflict level between the team and this agent is calculated for the issue of the team based on the average beliefs of the team and the outsider agent's beliefs. The links behave similarly to the normal links between the agents.
  Each of the actions are performed using 10% of the resources of the team and using the partial knowledge of the agents within the team. As mentioned before, the awareness and conflict levels are obtained through the team-outside agent links.
  The framing on causal relation likelihood grade is obtained using Equation 4.7, the state influence likelihood using Equation 4.11, the aim influence likelihood using Equation 4.9 and the impact influence likelihood using Equation 4.24
  All of the actions are graded and the action with the highest likelihood to occur is the action that will be performed. The impact of each of these actions is then given by Equation 4.8, Equation 4.12, Equation 4.10 and Equation 4.25.

### 4.2.5. Note on the agent individual belief actions

The agents which are part of a team can also perform actions as simple individuals similar to the actions performed in the backbone+ model. The resources used to this effect are the resources left depending on the belonging parameter. If the agent is team-less, then all his resources will go to performing individual actions.

The actions that the agent can perform are dependent on whether he has first chosen a policy or a problem similarly to the inter-team actions. In both cases, the agent can perform a state and aim influence action on other agents. Furthermore, if the agent has first chosen a problem, he will be able to perform a framing on causal relation action on causal relations related to the problem s/he has chosen. If the agent has first chosen a policy, he will be able to perform a framing on impact action on all the impacts of the chosen policy. The likelihood and impact equations used are the same as the ones presented in the inter-team actions section. For the external parties, all these actions are blanket actions acting on all agents.

### 4.2.6. The model cycle

The model cycle used when the three stream theory is considered is given below. The parts that are common to the common core are not detailed but they are repeated for a better understanding.

1. World round:
   (a) *World simulation*
   (b) *Trigger of external events*
   (c) *Update of the truth agent*
   (d) *Electorate action on policy makers*
   (e) *Transmission of the states*
2. Agenda setting round:
   (a) *Preference calculation (problems and policies):* Each agent calculates the preference for their principle and policy core beliefs (policy and problem). The agents then each select a problem or a policy that s/he will advocate for in his/her policy core beliefs based on the preferences calculated.
   (b) *Agent interactions:*
      i. *Resources received*
      ii. *Agent-team actions:* Each agent can decide to join or start a new team depending on his belief and his choice of policy or problem.
         A. *Belonging parameter update:* If an agent is in a team, then its belonging parameter is updated based on the latest beliefs.
         B. *Leave a team:* An agent will leave a team of his own accord only for one reason: if the belonging level drops below 30%. If the agent leaves the team he was part of, the team must then be checked to see if it has enough members. If it has less than three members it will have to be disbanded and all agents present in the team are removed from it.
         C. *Disband the team:* If the agent is the lead of the team, there is a possibility that he will disband the team. This happens when the policy issue the agent is advocating for changes and does not match the issue of the team anymore. This is checked every five ticks. If they do not match, the team will be disbanded and all agents removed from the team. The requirements used to create a team are also checked every five ticks to see if the members should still be in the team. If the number of members falls below three during this review process, then the team will be disbanded.
         D. *Join a team:* If the agent is not in a team, he will first try to join an existing team. For each team considered, he will spend a small amount of resources to gather information. If the gap in his beliefs is above the required thresholds for the issue that the considered team is supporting,

and his state belief are closed enough to the team's leader state belief on that issue, then the agent can join the team.

E. *Create a team:* If the agent has not managed to join a team, then he has the possibility to create a team himself. For this the agents looks towards the agents to which he is connected and has awareness. If the agent first chose a policy, then the agent will be able to start a team around that policy only. The same is true if the agent had chosen a problem. For each of these agents, the agent considers the gap in this issue along with the state to see if he shares beliefs with the other agents. Considering each agents costs a little resources for both the agent searching and the agents he is interacting with. Then depending on the personal strategy of the agent, the agent creates a team with all the agents he has found or he creates a team once he has found a sufficient amount of agents.

iii. *Team actions:* Each team performs their intra-team actions followed by their inter-team actions.

iv. *Network upkeep or maintenance*

v. *Belief influence actions:* All active agents perform their respective actions based on their remaining resources.

(c) *Preference calculation (problems and policies):* Each policy maker updates his preferences for his principle and policy core beliefs. This update of the preference is necessary to take into account the changes that might have occurred as a results of the agent interactions. Each policy maker then chooses first a problem or a policy with the highest preference as their issue of preference. They then select its associated policy or problem.

(d) *Agenda selection*

3. Policy formulation round:
   (a) *Preference calculation (problems and policies)*
   (b) *Agent interactions:*
      i. *Resources received*
      ii. *Agent-team actions*
      iii. *Team actions*
      iv. *Network upkeep or maintenance*
      v. *Belief influence actions*
   (c) *Preference calculation (problems and policies)*
   (d) *Policy instrument implementation*
4. *The model advances*

## 4.3. The advocacy framework coalition

The ACF introduces a number of new concepts. These concepts are an extension of the common core as was mentioned in the conceptualisation. They have no relation to the concepts presented in the three streams theory. The main new concept is the concept of coalition with is presented below.

### 4.3.1. Coalitions

The coalitions objects use a similar approach as the teams. A coalition is given as a 5-tuple written as: `(coalition ID, lead, members, issue, resources)` where `lead` is the leader of the coalition (the agent that created the coalition), `members` is the list of members that are part of the coalition, `issue` is the issue that the coalition is advocating for and `resources` consists of the resources at the disposal of the coalitions to perform actions. The resources are calculated as the sum of all the members belonging level.

The coalition are created based on the similarity of beliefs of the agents. Coalitions are created for each tick in the agenda setting process and the policy formulation process. In the agenda setting process, the coalitions are created based on their similarity of beliefs for a principle belief chosen by the modeller. For the policy formulation, they are created based on their similarity of beliefs regarding the issue that is on the agenda. These coalitions, similarly to teams, can perform intra-coalition actions and inter-coalition actions using the resources that the coalition has at it disposal from its members. The actions that the agents part of the coalition can perform as similar to the actions presented in the backbone+.

### 4.3.2. Coalition creation

There are several algorithms that can be used to create coalitions. One is proposed here. First the leader of any potential coalition is selected. This is done by selecting the agent with the most amount of awareness throughout his/her policy network. This agent is assigned as the head of a coalition and must then constitute a coalition. In the agenda setting step, the coalitions are formed around a common principle belief. This principle belief is selected by the modeller at the beginning of the simulation. For the policy formulation, the agents will be gathered around the policy core beliefs that is on the agenda. The leading agent will look throughout his/her network of agents and will select all agents that are within a certain threshold value of his/her own state belief for the concerned issue. All these agents will be added to the coalition by default. This decision by the leading agent is based on the perceived knowledge s/he has of the other agents. Note that during the creation of coalitions there is no exchange of knowledge between the agents. This is different than during team creation. This is because it is assumed that the leading agent looks through his network mentally and does not have to contact the different agents. This also means that the creation of a coalition is not a resource consuming process.

With the remaining agents present in the model which are coalition-less, the same steps are reproduced. The agent with the largest amount of awareness is selected and a coalition is created around him/her. These steps are repeated until less than 10% of the agents present in the model are left coalition-less.

The issue that will be advocated by the team is the one that the agent is supporting upon the creation of the coalition. Furthermore, the belonging level of the agents is calculated based on the issue being advocated by the team. This belonging value is calculated as the difference between the leader agent and their own belief values. This also means that the leader of the coalition will always have a belonging value of 1.

### 4.3.3. Intra-coalition actions

There are three main intra-coalition actions. These are the blanket framing of causal relations of the issue the coalition is advocating for, and aim and state influence actions on individual agents. These actions are performed in the same was as was presented in the three streams theory for the teams. These actions are the same in the agenda setting and the policy formulation processes. The difference relates to the issue that are being influenced only. Furthermore, the actions assessed are the ones that the leader of the coalition would make, and their assessment is based on the leader partial knowledge and his/her connection to the other agent. It is a centralised process.

### 4.3.4. Inter-coalition actions

The actions that can be performed by the coalition on agents are also limited to the three actions. These are framing on causal relation actions, and aim and state influence actions. These are once again similar to the actions presented in the three streams theory for the teams. The main difference in on how the actions are selected. Within the coalition framework, the actions are decided by the leader. Not all agents present in the team are consulted. Only the leader looks at the possible actions and implements the actions. It is therefore important that the leader have a robust policy network.

### 4.3.5. The ACF cycle

The policy cycle that is used for the ACF is detailed below. The main difference with the backbone+ policy cycle is the addition of coalitions-related steps.

1. Tick initialisation:
    (a) *World simulation*
    (b) *Trigger of external events*
    (c) *Update of the truth agent*
    (d) *Electorate actions*
    (e) *External parties belief update*
    (f) *All agents belief update*
2. Agenda setting:
    (a) *Agent issue classification and selection*
    (b) *Deliberations:*
        i. *Resources received*
        ii. *Creation of the coalitions:* Agents are assigned to specific coalitions depending on the deep core belief of interest selected by the modeller.
        iii. *Coalition belief actions:* Each of the coalitions can perform their belief actions. These are once again split between the intra- and inter-coalition actions.
        iv. *Policy network upkeep or maintenance*
        v. *Individual belief actions*
    (c) *The policy makers rank the issues*
    (d) *Agenda setting*
3. Policy formulation:
    (a) *Policy pool selection*
    (b) *Policy instrument selection*
    (c) *Deliberations:*
        i. *Resources received*
        ii. *Creation of the coalitions*
        iii. *Coalition belief actions*
        iv. *Policy network upkeep or maintenance*

v. *Individual belief actions*

(d) *The policy makers rank the instruments*

(e) *The system decides if a policy instrument should be implemented*

4. *The model advances to the next time step*

## 4.4. Feedback theory

The feedback theory focuses mostly on the policy instruments. It activates one attribute of these instruments: `feedback`. The feedback parameter defines what additional feedback can be expected from the measure. This feedback attribute is then formed of three parameters: `citizenship, groups and agenda`. This represent each of the feedback concepts taken into account in the model: impact on the electorate composition, impact on the resource allocation for policy entrepreneurs and impact on the knowledge of the belief tree respectively.

Not all feedback attributes need to be used for every instrument. This is up to the modeller to decide based on expected feedback of the instrument chosen. The different attributes are given below:

1. The *citizenship* attribute relates to the variation of the representation attribute of the electorate when applying the instrument. The electorate targeted along with the increase of decrease percentage of that electorate is specified within this attribute.
2. The *groups* attribute relates to the resources provided to the different groups of policy entrepreneurs and policy makers receive each round. Within this attribute, Within this attribute, the political affiliation considered is mentioned along with the percentage increase of decrease in the resources attributed to it. Note that this feedback does not apply at the agent level but at the political affiliation level.
3. The *agenda* attribute relates to the issues that the awareness attribute of the issues within the agents' belief trees. This attribute can change the awareness of specific agents to the issues in their belief tree. Depending on the feedback effect chosen, it will set the issue awareness to 1 for issues that are new to the agents and to -1 for issues that are removed from the agent's belief hierarchy. Note that this feedback effect applies to the entire subsystem at once and not to specific agents within a subsystem. Furthermore, it can affect more than one issue at a time depending on the modeller's inputs.

The feedback theory is considered to be an extension of the ACF and the three streams theory. It is therefore advised to use it with these theories and not only on the common core model. On its own, the effect might be limited or not apply at all.

## 4.5. Diffusion theory

The introduction of the diffusion theory brings in different concepts. The first important point is the fact that diffusion theory require a set of subsystems. Together they form the system. Each of these subsystems has its own policy network are presented above with a set of agents. Each agent has a certain belief hierarchy which is common to agents through the entire system (and so all subsystems). The policy instrument set used by the modeller is also a set used by the agents systemwide. Finally, each subsystem has a `status` attribute. This represent the influence of each of the subsystem and allows to assign resources that are used by the agents for the diffusion actions. Subsystems with a higher status will see its agents granted more resources compared to subsystems with a lower status. The two other main concepts are the super-policy network and the subsystem network. They are presented within this section.

### 4.5.1. Super-policy network

The super-policy network is a network that is modelled similarly to the policy network. However, it consists of links only connecting agents which are in different subsystems. The links attributes within this network are the same as the one in the policy network. The same maintenance actions are also performed within this network. Note that initially, this network is much sparser than policy networks. Furthermore, the awareness decay is also much lower than for other systems to maintain a large network without the need for constant maintenance.

### 4.5.2. Subsystem network

The subsystem network is a network similar to the affiliation network between the political affiliations. It is however composed of directed links between the different systems. This network is exclusively used in the context of the diffusion theory as it requires numerous subsystems. Each link is has a certain type which defines the directed relationship between two subsystems. It can be friendly, dominant, competitive or coercive. More details are provided later on in this chapter. The different links, and the actions that can be performed by agents based on the relation between the subsystems are explained below. Similarly to previous models, the likelihood calculations for each of these actions are based on the agent's partial knowledge of other agent's beliefs. Furthermore, the agents influence agents in their network on the issues they think are relevant to them in their own subsystem. There is no systemwide agenda or policy instrument implementation.

**Friendly link** When an agent from system 1 interacts with an agent from system 2 and the link from system 1 to system 2 is friendly, the action performed will be very similar to the actions performed within the policy network. The actions possible will depend on the accompanying model. For the three streams models, the actions can be causal relation framing, impact influence, states influence or aim influence actions. For the ACF, the actors are limited to casual relation framing, state influence and aim influence. The aim within such a link is to have policy learning between the agents. The likelihood and impact of these actions are calculated similarly to what was previously shown.

**Dominant/coercive link** If the link is a dominant or coercive link, then the actor will impose his/her aim parameter on the other agent. This means that the agent will literally change the value of the aim of the actor s/he is linked to. The change will be much stronger than for a simple friendly link action. It is still dependent on the same parameters as before but to a less extent. The actions available to the agents are the same as the actions in the friendly link case. However, some changes are added. The likelihood of performing an action does not depend on the political affiliation anymore or the awareness. It is only based on the conflict level. Furthermore, an added coefficient is placed on the impact. This coefficient is chosen by the modeller and is meant to make the impact of the actions much more potent than the action would be in a friendly link. The different equations are given below for the likelihood:

$$
\begin{aligned}
G_{CW,n_m} &= conflictLevel_{CW,n,m} \cdot actionWeight_{n,m} \\
G_{I_{issue},n_m} &= conflictLevel_{I_{issue},n,m} \cdot actionWeight_{n,m} \\
G_{S_{issue},n_m} &= conflictLevel_{S_{issue},n,m} \cdot actionWeight_{n,m} \\
G_{A_{issue},n_m} &= conflictLevel_{A_{issue},n,m} \cdot actionWeight_{n,m}
\end{aligned} \tag{4.34}
$$

And the impact for each of the actions is given by:

$$
\begin{aligned}
CW_m &:= CW_m + (CW_n - CW_m) \cdot resources \cdot coercionCoef \\
I_m &:= I_m + (I_n - I_m) \cdot resources \cdot coercionCoef \\
S_m &:= S_m + (S_n - S_m) \cdot resources \cdot coercionCoef \\
A_m &:= A_m + (A_n - A_m) \cdot resources \cdot coercionCoef
\end{aligned} \tag{4.35}
$$

Where $coercionCoef$ is the coercion coefficient which is dependent on the link considered. This coefficient is different between coercive links and dominant links.

**Competitive link** If the link is a competitive link, then the actor will seek to change his/her own beliefs according to what s/he sees in another actor in a different system. The actor in system 1 will inspect the states of the actor in system 2. The action will consists of the first actor adjusting his/her aims to match the states of the second actor. The amount of adjustment will be dependent on the aforementioned parameters. This action is meant to display a need for the first actor to reach the same state as the one present in the second system. It is a competitive relationship. The likelihood and impact are obtained in the same way as for friendly links. However, the impact is not on the agent being acted upon anymore but it is applied to The agent acting. His/her beliefs are influenced by him/herself.

As done previously, each agent considers all possible actions for the different agents that are in his/her super-policy network. All likelihoods for all actions, regardless of the type of links between the subsystems in which the agents are, are calculated. The action that has the highest likelihood grade is then selected and the action is implemented.

The use of the diffusion theory is similar to the use of the feedback theory. Although it can be used without any other policy making theories, it is advised to consider either the three streams or the ACF theories with the backbone when using the diffusion theory.

### 4.5.3. The diffusion cycle

The cycle that is used for the diffusion must also consider all cycles of all subsystems. The assumption is that all internal decisions within the subsystems are performed prior to the diffusion-related actions. This means that actions that are performed at the system level will only have an impact on the subsystems within the next time period. The cycle is shown below:

1. Tick initialisation:
   (a) *World simulation*
   (b) *Trigger of external events*
   (c) *Update of the truth agent*

   (d) *Electorate actions*
   (e) *External parties belief update*
   (f) *All agents belief update*
2. Agenda setting:
   (a) *Subsystem related actions:* Each of the subsystems perform their agenda setting related actions.
   (b) *System deliberations:*
      i. *Resources received*
      ii. *Super-policy network upkeep or maintenance*
      iii. *Individual belief actions*
3. Policy formulation:
   (a) *Subsystem related actions:* Each of the subsystems perform their policy formulation related actions.
   (b) *Subsystem related actions:* Each of the subsystems perform their agenda setting related actions.
   (c) *System deliberations:*
      i. *Resources received*
      ii. *Super-policy network upkeep or maintenance*
      iii. *Individual belief actions*
4. *The model advances to the next time step*

Note that this cycle assume that there is only one world simulation for the entire system. In cases where the world simulation are also defined per subsystem, then the world simulation will be performed one by one in the tick initialisation phase and each subsystem will see its states updated accordingly.

# II

# The Model Simulation

# 5

# Model Implementation

In the previous chapters, the model has been conceptualised and formalised. The next step is to implement this model. An agent based approach is used for this implementation and it is coded using the Python language. This chapter first details the reason why an agent based approach is used in Section 5.1. Section 5.2 then goes over the approach used for this implementation by looking at the world model and the policy emergence model. In Section 5.3 the forest fire is explained in more details. Section 5.4 follows with an outline of the different model parameters that have to be taken into account. Section 5.5 compiles the pros and cons of using Python for this implementation. Finally, Section 5.6 describes the steps that were used to verify the implementation.

## 5.1. Agent Based Models

Agent-based models (ABM) are a type of modelling method that uses autonomous agents. They are independent agents that can take their own decisions. The agents are backward looking and their decisions are governed by simple rules. Each of the agents can assess their situation and communicate with the other agents present in the model, (Bonabeau, 2002; Macy and Willer, 2002; van Dam et al., 2012). The models are usually iterated in ticks. A tick represents a time $t$ at which the agents can communicate with each other and perform actions. Once all actions are performed, the model moves to the next tick. The time representation of the tick can be different in every model. In some model, a tick can represent five years of time while in others it can represent only a few seconds (Siebers et al., 2010).

Agent based models are used in a wide range of disciplines and for a wide range of topics (Helbing, 2012). These range from socio-economic to collective intelligence models while considering urban and regional development or coalition formation. Prior to ABM, modelling and simulation was rare in the domain of social and economic sciences. Having the ability to be used as a qualitative method, ABM can be used to model system in these domains, (Helbing, 2012; Macy and Willer, 2002).

There are several advantage to the use of ABM, (Bonabeau, 2002; Brailsford, 2014; Helbing, 2012). Agent-based models can help capture emergent phenomena. This is the result of the actions of the different agents. The collective results are different than the individual actions of the agents. These emergent phenomena are counter-intuitive. This makes them hard to model and it is one of the reason ABM is preferred when such behaviour is expected. An example of an emergent phenomena is herd behaviour. The actions of different agents can, after some time, end up coordinating. In effect, the system is more than the sum of its parts (Helbing, 2012).

The second advantage of ABM is the fact that it can help provide a natural description of the system. In a lot of cases, ABM will seem to relate reality to the model more directly. This can be due to the fact that in the real world, humans are the ones making the decisions. Similarly, in an ABM model, it is agents that are making the decisions. Furthermore, other modelling methods will tend to use aggregate parameters which can be abstract and unrepresentative of reality. This goes further when once considers the visualisation that accompany ABMs. These can help the model and the results appear more believable.

The third advantage of ABM models is that they are flexible. The models being built can be modified fairly easily. The level of aggregation of the level can therefore be played with during the conceptualisation of the model. The flexibility of these models can also be related to the fact that it is easy to add or remove agents from the models.

There are also disadvantages to using agent based models, (Bonabeau, 2002; Helbing, 2012). These simulations remain models with all the disadvantages that accompany them. The design and construction of such a model will depend on the person making the model. The right level of detail and aggregation needs to be pursued to obtain valid results. This is more an art than a science.

A second problem relates to the fact that these models can attempt to model humans. Humans cannot be modelled perfectly. Only limited part of their decision making process can be modelled in such models. This can affect the degree of accuracy of the results from the model. One should also be wary of the models built and the way their results can be interpreted. In some cases, it is more important to look at the results qualitatively while in others, it can be important to look at the results quantitatively.

Although ABM can be an appropriate method for certain models, the nature of the models will lead to large computing times. Because the agent based models model agents and each agents has to go through its rules for each tick, the computational efficiency of ABM can be low and the model run times can be long. This is compounded with the need to perform repetitions for each run to account for uncertainty and to assess the robustness of the model.

Finally, despite appearances agent based models are not meant to be used for prediction purposes. Instead, they are designed to help the modeller provide an explanation on the system being modelled or to provide additional understanding in the phenomenon being modelled, Sanchez and Lucas (2002).

There are examples of the use of agent based modelling for the emergence of policies in the literature. Once of which is the MAIA framework developed by Ghorbani et al. (2013). However, the model developed for this framework based on based on institutional analysis theory. This is a different approach that the one taking here looking at policy making theories. Furthermore, the aim is not to develop a framework as the theories on which the model is to be based are not as widely accepted at the Institutional Analysis and Development framework (IAD) from Ostrom (1995).

Agent based models are considered for the implementation of the model because of the approach taken in the formalisation. The model contains a number of agents that can perform actions on one another. Furthermore, the study is about emergence and there is an expectation of policy emergence. The disadvantages of agent based model should however be a warning. Considering the complex formalisation, it is expected that the model be computationally inefficient.

## 5.2. The General Approach

The general approach that is taken for the implementation of the model is similar to the one that was presented in the conceptualisation and the formalisation. The model presented here combines a world model and a policy emergence model. The world model that is selected is a forest fire model. This model is chosen for its simplicity and its ability to be coupled to the policy emergence model. More details are provided in Section 5.3.

There are three main parts to an agent based model. First there is the initialisation of the model. This is done at the beginning of each simulation of the model. In the present case, it concerns the creation of the agents, the creation of their initial values, the generation of the policy network, the introduction of the policy instruments and the generation of the world where the forest fire will occur. This happens only once per simulation. The second part consists of the ticks that will be run over and over throughout the simulation. What happens in one tick is what was described within the formalisation cycles. It is further expanded below. The third part of the model is the collection of the data. This process occurs at the end of each tick. The data that the modeller has specified is collected and exported for analysis later on.

### 5.2.1. Single tick steps

One tick is split into four main parts: the tick initialisation, the agenda setting, the policy formulation and the end of tick procedures.

The tick initialisation deals with the world model simulation, the bridge that brings the states from the world model to the policy emergence model and the update of the states of the different agents. First, the world simulation is run. In the present case, one tick of the forest fire agent based model is simulated. Then, the truth agent which acts as the bridge between the two models assesses the states based on observations of the model. The truth agents gather the states for each of the issues present in the belief hierarchy and maps them onto a [1-, 1] interval. This mapping can be tuned by the modeller. The truth agent then provides the states, as calculated, to the external parties which are in charge of distributing the information to the other agents. Once all of this is done, the tick initialisation is complete.

Then comes the agenda setting. In this step, the agents have for task to decide what will be on the agenda. Each agent selects an issue that s/he will be advocating for. The agents then interact based on that issue. At the end of the agenda setting, the policy makers update their issue preferences based on how they were influenced. They then go on to decide what is on the agenda based on the issues they have each chosen.

After the agenda has been obtained, the model moves to the policy formulation which is considered as a different political arena. This means that different issues are considered based on what is on the agenda. There, the agents select a policy instrument based on their preferences. They can again interact and influence one another. At the end of the policy formulation step, the policy makers update their preferences and each choose an policy instrument. If a sufficient number of policy makers have chosen the same policy instrument, it is implemented into the world model. If not, the model moves on to the end of tick procedures.

In the end of tick procedures, different parameters are updated. This is the case for the awareness level in the policy network depending on the awareness decay. The data is also collected at this point of the model.

The approach presented here has embedded the forest first model within the policy emergence model. As mentioned before, the forest fire model is also an agent based model. It is simulated on the same time period as the policy emergence model. This choice is made because the policy emergence simulates two weeks for one tick. If the amount of weeks simulated was longer this would have to be re-assessed and the forest fire model might need to advance more than one time step for every policy emergence time step advancement. Further work could look into the impact of this time coupling for specific case studies and see what impact it has on the results. Furthermore, the coupled models do not have to both be agent based models. Different simulations could be coupled to the policy emergence model as long as issues are present and they can be mapped on an interval [-1, 1].

### 5.2.2. The models implemented

Four models are implemented based on the formalisation. They are used to test and simulate the process of policy emergence. Because of time constraints, the feedback theory and the diffusion theory were not implemented in the agent based models. They remain at the state of the formalisation and can be implemented by future researchers.

The first model considered is named the backbone. This model is the smallest possible model that can be used to show policy emergence. This model is not derived from the theories but is derived from the formalisation itself. This model is limited in its scope and is used for verification and comparison purposes within the results chapter.

The backbone model only contains policy makers as agents, one external party to transfer the states of the world to the policy makers (but barred from performing any actions) and the electorates. This approaches provides a model that can demonstrate policy emergence through the implementation of policy instruments to affect the world. However, no active interaction is performed between the agents and therefore, the agents' beliefs remain stable throughout the entire simulation beyond the passive influence of the electorates.

The second model considered is called the backbone+. This model is the model implementing the common core from the formalisation. This model uses the same cycle as the ACF model presented in the formalisation. However, it does not introduce the concept of coalitions and their associated actions. This model is used also as a means of comparison and as a benchmark for the ACF and the three streams model.

Finally, two other models are implemented. The third model is the three streams model as presented within the formalisation. This model adds the concepts of policy hierarchy and teams to the backbone+ model. It also introduces variation in the possible actions as shown before. The fourth model is the ACF model also as presented in the formalisation. This model introduces the coalition concept to the backbone+ model. All these models are implemented and their results compared in Chapter 7.

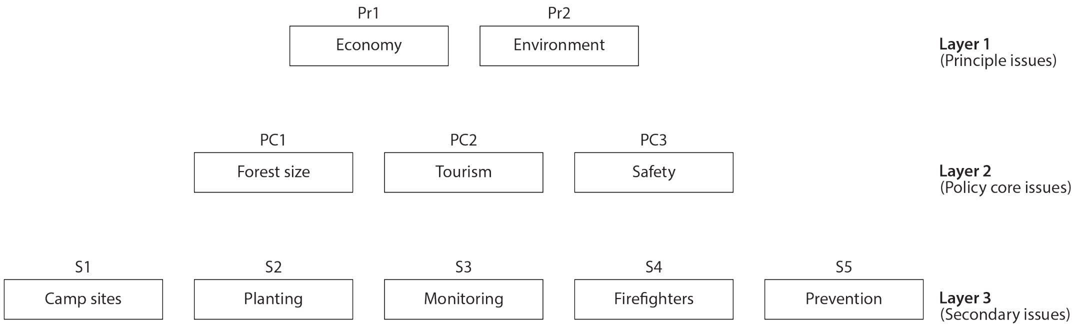


Figure 5.1: Belief hierarchy used for the forest fire world model.

## 5.3. The Forest-Fire Model

The world model implemented is a forest fire agent based model. This model is a classic simple example of agent based modelling. The model selected was obtained from the Mesa Project[1] but was adjusted for the purposes of the experiments with the policy emergence model. The forest fire model is a model that contains several hundred cells. Each cell can take several states. Depending on these states, there is a certain probability that a fire might occur for specific cells and spread to neighbouring cells. Each of the cells can take one of six states:

- Empty cell: The cell is left empty and can therefore not burn.
- Thin forest: This is a low density forest patch which has a low probability of burning. Thin forests become thick forests after a certain period of time defined by the modeller.
- Thick forest: This is a high density forest patch which has a high probability of burning.
- Burning: This is a temporary state. After this state, the cell will immediately take the burnt-out state. Note that this process can be affected by firefighters as mentioned later on.
- Burnt-out: This is a burnt patch that will ultimately regrow into a thin forest or remain empty over time.
- Camping site: This is a cell filled with a camping site. Such a cell has a high probability of burning. Camping sites help tourism and can only be built through measures from the policy makers. Once burnt, they cannot return to being camping cites.

There are several additional elements to the model. Firefighters are present within the model. They can reduce the impact of a fire and instead of leading to a burnt-out cell, they will extinguish the fire which leads to a thin forest cell. This is based on a probability defined by the modeller.

To integrate the forest fire model with the policy emergence model, several steps are undertaken. The first one is to create a belief hierarchy for the agents (truth agent, electorate, external parties, policy makers and policy entrepreneurs). The belief hierarchy constructed is shown in Figure 5.1. The first layer of the hierarchy, with the principle issues, is composed of the economy and the environment. The second layer, the policy core issues, is composed of the forest size, the tourism and the safety. Finally, the third layer of the hierarchy, which uses the secondary issues, is composed of the camp sites, the planting of more hierarchies,

[1] `https://github.com/projectmesa/mesa`

the monitoring of the cells, the amount of firefighters dispatched, and the prevention of fires. Each of these issues is associated with specific parameters within the model.

It is from this hierarchy that the agents will select the issues and problems they advocate for. Within the policy emergence model, the instruments provided by the modeller all impact the secondary issues presented in the hierarchy. Based on these impacts, the agents can grade each instrument and select the one they find most appropriate. In the world model, such instrument can have a broader or different impact. For example, increasing the number of firefighters will only affect the fourth secondary issue in the belief hierarchy (see Figure 5.1) when calculating the impact of the instrument from an agent point of view. In the world model however, adding more firefighters can also impact the amount of tourism, increase the safety of the forest, increase the economy and environment.

Additional information on how each of the states for these variables are calculated are provided in Appendix C. The different policy instruments are also shown there. In the case where the modeller would consider a different world model for a different case study, this entire formalisation would have to be built from the ground up again. The policy emergence model will however remain the same (other than the tailoring of the inputs for the model agents and for other parameters that make each use of the model unique). In most cases, the world model will already be provided by a third party. The modeller will have to build a belief hierarchy based on that model along with providing a set of policy instruments and specify how the different states for each of the issues in the belief hierarchy be measured. For the policy instrument set, the modeller will have to provide their impact on the world model but also in the policy emergence model. If an inadvertent mismatch exists between the two impacts, issues will arise when simulating the model

## 5.4. The model parameters

There are a number of exogenous parameters that can be used to simulate different types of behaviours in the model. There are three main types of exogenous parameter with respect to the full agent based model: parameters related to the world model, parameters related to the bridge between the world and policy emergence models and parameters related to the policy emergence model.

The parameters related to the world model relate to the tuning of the world model. They define the initial values for that model but also the time between different events. The parameters used for the bridge relate to the calculation of the states for the actors and the impact of the instruments. For specific instruments certain maxima or minima can be set to avoid having unrealistic results within the world model and to make sure that the states will remain within the [-1,1] interval.

There are many more external parameters that are related to the policy emergence model. Each policy making theory has its own set of parameters that can help define everything from the belief hierarchy inputs to the strategy that an agent will choose when selecting a team in the three streams theory. These parameters are wide ranging and all have default values. They can however be modified by the modeller so as to make the model more geographically specific to the system being studied or to the actors being modelled. These parameters help make the model appropriate for different policy network behaviours which will vary depending on the case study. The full list of parameters that can be changed is presented in its entirety in Appendix D.

## 5.5. The Use of Python

Python is a programming language that dates back to 1991. It is an open source language that is used widely around the world and which is becoming increasingly attractive within academic fields. Within the context of agent based models, Python is a fairly new language. The programming software of reference for such models is NetLogo and uses a subset of the Java language.

Several reasons can be used to justify the use of Python instead of NetLogo for the model implementation within this report. The first relates to the flexibility that is inherent to the use of Python. Considering Python is widely used for other applications than agent based modelling, a lot of tools can be used with the language. A large number of file inputs can also be used with Python. The potential of Python is virtually limitless and is much less restricted than what NetLogo can do. This is particularly interesting considering that the world model might not always be simulated within Python or using an agent based model. It allows for more coupling possibilities.

Regarding the coding of the model itself, Python is a more suitable language to use considering the data structure that is required to model the agent's belief systems. Python allows for the use of a variety of different data structures that can be used depending on the requirements. This is not the case for NetLogo.

Python is used because of the ultimate sharing objective of this project. The aim is to widely share the model. It is built such that other researchers be able to add modules, provide feedback or make modifications to the model. Python makes such an effort easier. as it is a more widely known programming language. It also allows for more flexibility considering the number of parts and the model size.

As is shown in subsequent chapters, the amount of inputs required for this model is large. The use of Python allows for an easier use and introduction of these inputs within the model. This is due to the different data structures that can be used depending on the case study or inputs considered and to the larger availability of input files. Python is therefore superior in this regard to NetLogo.

There are however drawbacks to the use of Python, mostly related to the logistics around agent based modelling. The coding of an agent based model follows a certain framework as mentioned before. Although this framework is perfectly implemented in NetLogo, it is almost entirely absent from Python. In recent years, one effort has been made to present an agent based framework in Python. This was done by Project Mesa[2]. They have developed a Python agent based framework that allows for the construction of simple agent based models which perform the critical steps of an agent based model but also allows for the live display of the results on the browser.

Furthermore, NetLogo comes with a large array of visualisation tools specific to agent based models. These visualisations can show live what is happening in the model. This is currently not the case for Python. The Mesa Project visualisation is limited and this visualisation cannot be used for a wide range of agent based models without large modifications. Any type of visualisation in Python would require considerable time to code as, without a framework, each case study would require its own visualisation. This is an important drawbacks for using simple agent based models which gain in understanding when looking at the visualisation as the simulation is ongoing. It is also a limitation for testing and verifying the code being implemented.

[2] `https://github.com/projectmesa`

The model coded in this thesis uses the framework originally developed by the Mesa Project and builds on it extensively. The basic structure was kept but aspects such as network functionalities or behaviour space introduction were added along with the addition of the possibility to use an extensive input file to simulate different types of experiments. This lead to some limitations such as the loss of live browser visualisation or inputs through a graphical user interface. Such functionalities are still possible and can be added at a later stage but are not considered to be within the scope of this thesis.

## 5.6. Model Verification

An extensive and rigorous verification process was conducted alongside the writing of the code for this model. The verification was done in parallel due to the size of the model and the impossibility to do all of the verification after coding. The main method of verification was a verification through `print` functions. For almost all of the lines of code in the model, the `print` function was used to check whether the expected outcomes were seen from the different operations. A lot of this `print` function infrastructure still remains in the comments of the code and can be uncommented to perform additional verification checks.

Several categories of checks were performed for this verification. The first ones are related to the forest fire model. It was checked that the states calculated from the world model never went above one or below minus one. This was tested for numerous extreme cases, nonetheless a warning still remains in the code in the cases of this happening. A check was also performed on the implementation of the instrument which is also considered to be part of the world model. It was made certain that they were implemented appropriately and led to changes in the world model.

The second checks were performed on all parts of the code that included the belief hierarchy. This is considered to be the most important part of the verification due to the fact that the choice of the wrong index would not break the code but instead introduces errors in the simulation. For example, if the indexing of the causal relations in the partial belief hierarchy of the second actors are mistaken for another causal relation, the code would still run but provide erroneous outputs. The use of the belief hierarchy was therefore extensively verified through the checking of the indexes selected in all lines of code that used the belief hierarchy. Some of the infrastructure used for this verification still remains in the code at this moment. These verification impacted most parts of the code from the preferences calculations to the instrument selection and the actions implementation.

The third checks that were performed were on the actions grading, selection and implementation. Several verification checks were performed there to make sure the actions were graded appropriately, the right action was selected and the right action was implemented by the right agent on the right agent. The action selections comes back throughout the model in different forms. Several times, actions are performed from one agent onto other agents for causal relations and issues. This happens both in the agenda setting and formulation processes. Restrictions are required for the policy formulation step where the causal relations considered are restricted (only actions on causal relations related to the item on the agenda can be performed). For these actions, the verification was fairly simple as the number of actions were limited by the number of issues, causal relations and agents in the model. A more crucial verification was the actions performed in teams. For such actions, all of the agents in the team perform actions on all of the agents outside the team. This can lead to a grading list of actions of several hundreds of entries. It is then important to pinpoint which action is which performed by whom and on which agent. This was extensively checked to make sure the appropriate actions were performed. If incorrect, the code would once again still work but the policy learning would be greatly affected as the wrong actions would be implemented.

Extensive verifications were also performed on the agent-team actions and the coalition creation. For the three streams model, the creation, disbanding and checking of teams is extensive and complex. Each steps contains a number of checks for the creation or disbanding of teams. This was checked thoroughly by removing agents on purpose, adding agents on purpose or changing their beliefs such that they would not belong in a team anymore. Several issues were found when disbanding teams and were fixed. Similarly for the coalitions, the appropriate creation of the coalition was checked such that all the agents that should be in a coalition are present in that coalition.

Additional verification steps were taken when considering the networks. The policy network awareness and awareness decay mechanics were verified. The shadow networks used for coalitions and teams were also checked. These networks are the temporary team and coalition networks. An extensive verification process was also conducted to make sure the appropriate data was saved from all the potential outputs from the model. The code that was constructed for the inputs in the case of experiments was also verified to make sure the change inputs was appropriate for each of the runs. The overall verification process is presented in more details in Appendix E.

# 6
# Exploration and Experimentation

Once the model has been constructed, it is possible to look into how this model will be used. The first task for this is to select endogenous parameters that will be recorded. The different parameters of interest will be used to analyse and discuss the results. They are presented in Section 6.1. The model warmup is considered in Section 6.2 along with how the randomness is addressed in Section 6.3. Before experiments are conducted, it is important to understand whether the model behave in a specific manner when using extreme variable. This is looked at in the exploration phase in Section 6.4. Then it is possible to perform different experiments to attempt to display concepts that are present in the literature and that should be expected from the formalisation. The base case experiment performing a variable sweep is presented in Section 6.5. The experiment dealing with external events are then presented in Section 6.6. Finally, limitations are expected from these experiments and they are outlined in Section 6.7.

## 6.1. The Endogenous Parameters

The model produces and uses a large number of endogenous parameters. A lot of these parameters can be used to analyse the model. Considering the model is split in several parts, these parameters can be categorised in different parts. For the analysis of the results, there will usually only be a need of a certain set of these parameters. This will depend on the aim of the modeller in the analysis. A modeller that looks at the policy network evolution, will have little interest in parameters linked to policy learning for example.

The first set of parameters relates to the world model in this thesis' context. These are the parameters that defined what is in the forest fire model. These parameters change for every different case study. It encompasses parameters such as the number of cells in each of the state (thick forest, empty, thin forest, ...). It also considers the coefficients that can be affected by the agents in the model such as the probability for a camp site to catch on fire or the probability that a burning cell will be extinguished. Note that some of these parameters are initially set by the modeller but because they are modified by the agents afterwards, they can also be considered endogenous. These are, in short, the dynamic states of the world model under investigation.

The second set of parameters is related to the emergence model itself. These are mostly parameters that are derived from the decisions of the agents. This is the case for the agenda which is composed of an issue or a policy and a problem for the three streams theory in particular. It also contains the selected instrument at the end of the policy formulation and the truth belief hierarchy which is composed of the raw states directly obtained from the technical model.

Then come the parameters related to the agents. There are several of these parameters with the most important being the belief hierarchy of the agent. This belief hierarchy contains both the beliefs of the agent but also what the agent thinks are the belief hierarchy of the other agents present in the model. These hierarchies are also referred as the partial knowledge hierarchies. In the case of the three streams model, these belief hierarchies are supplemented with policy hierarchies. Each of these are also split in two parts. The partial knowledge here relates to the impact beliefs of the other agents. Each of the agents also has a certain amount of resources based on their affiliation and the current political representation within the system. Then, for the three streams theory and the ACF, the agents will have a specific belonging level if they are part of a team and when they are part of a coalition. This belonging level can help understand the dynamics of the teams and coalitions and their political power within the model.

There are also a number of parameters related to the policy network. This policy network is there by default but not necessarily fully populated by links. This will vary on awareness level for each of the links. Note that right now, the policy network is randomly generated which makes it an endogenous parameter. In the future, it is in the interest of the modeller to have it as an exogenous parameter to better represent a case study. Separately, for each issue in each links, the agents will have a certain conflict level. This conflict level might also be different from agent A to agent B and from agent B to agent A. In the case of the three streams theory and the ACF, shadow networks are also temporarily created between teams and coalitions, and the agents that are not in these teams and coalitions. These are referred as shadow network in Chapter 4. These network possess the same behaviour and parameters as the normal policy network. It is currently not possible to save data from the shadow networks but this could be changed if there is a need for it.

Finally, there are parameters related to the teams and the coalitions for the three streams theory and the ACF. For teams, these parameters are the amount of resources, the time of creation, the members and the issue being advocated for. Each of these parameters, when studied, can help understand the team dynamics at play. It can also provide insight in why a certain instrument was chosen over another. For coalitions similar parameters are present.

A large set of parameters regarding the actions of the agents could also potentially be considered. However, these recording of these parameters has not been implemented. These are all parameters related to the actions that the different agents perform. It could be useful to save which actions are performing the action, their impact, which actor was influenced by the action. This could help understand the steps that occurred in the beliefs of the agents. It is shown later in this report that such data output would be crucial to get a better understanding of the results.

To be able to focus the analysis of this model, not all parameters are being considered as potential outputs. A selection has to be made such that the analysis can focus on specific aspects of the model. Within the scope of this thesis, the aim is to show that the broad concepts present in the literature are present in the model. The parameters of interests are therefore limited. All model parameters are used along with the agent's own belief hierarchy for each of the models. For the backbone+ model, network parameters such as awareness and the agents on both end of the links are also selected. Then for the three streams theory and the ACF, parameters of resources, issue and members are selected. Team and coalition parameters are also saved. The rest of the parameters are not considered to be of interest. The entire list of the parameters present in the model is in Appendix D.

The selection performed here is very specific. Different modeller with different aims can have a different parameter interest which would result in a very different list. The model has enough complexity enough to allow very different analysis depending on the focus of the modeller.

## 6.2. The Model Warmup

Due to the nature of the model and the nature of agent based models, a warm up time is sometimes necessary. The warm up time is the time it takes for the model to get to a certain state where one considers the models to be close to a state comparable to reality. This is particularly important within the policy emergence model for the beliefs of the agents. The actions of the agents are eminently driven by their knowledge of other agent's belief. If the model were to be started without start up time with empty partial knowledge, it could then take upwards of 1000 ticks for the model to reach a state where all the agents have a certain amount of knowledge on all the beliefs of the other agents. This kind of warm up time is too long to be considered practical for any experiment considering that a run is chosen to be 500 ticks only.

Alternatives are available to drastically reduce the warm up time but none of these alternatives are perfect. The main aim of these alternatives is to populate the partial knowledge of the different agents as close to what they would be in reality. This can be done through several methods like statistically distributing the partial knowledge for each issue based on the actual beliefs of the agents and skewed depending on the affiliation of the other agents. It can also be populated randomly with number on the interval [-1, 1]. The method used here was to assign the partial beliefs as equal as the real belief of the agents but with a certain amount of uncertainty, a random number within $\pm$ 1 of the value. The quality of these partial belief initialisation methods and of the warm up time could be studied on its own depending on the method to observe what the effects of different partial belief initialisations are.

## 6.3. The Model Randomness

Most of the inputs into the model are randomised to a certain extent. This is the case for example for the belief hierarchy of the agents which are originally provided by the modeller. The aims of the agents are randomised by adding a number between +0.1 and -0.1 randomly selected to all agents. This is done to have a slightly different simulation every time and therefore see how sensitive the model is.

This is also the case for the starting position for the forest fire model. The state of each of the cells is randomly assigned based on a certain probability along with their location in the grid. This means that every run will be slightly different.

The policy network is also generated randomly. This means that for each simulation, the links connecting the agents will be different along with their awareness level. A certain percentage does have to be met for inactive links, zero links and active links.

For the experiments performed here, the randomness is left for most of the parameters mentioned above. However, the randomness is removed from the policy network creation. The reason behind this decision is that the policy network is an important part of the model. Having a different policy network for every run would be like changing a major parameter every run on top of the other parameters being tested. It would blur the results and reduce the possibility of understanding and explaining the results.

## 6.4. The Model Exploration

To understand the behaviour of the model and to check whether the model can break in extreme situation, a model exploration is performed. For this exploration, a set of parameters is given extreme values unlikely to happen in reality. The parameters selected vary depending on the model being considered. For the model exploration, the aim is to set these parameters to extreme values to observe whether the model results are as expected and to see if any parameter could break the model in a significant way.

The number of agents that is being considered within the model exploration but also for the experiments later on is 31. The distribution is given as follows: six policy makers, six external parties and 18 policy entrepreneurs. Note that it was chosen to have three policy entrepreneurs per policy makers. The distribution of agents is kept constant to simplify the comparison between the different models. This set of agents also leads to a reasonably sized policy network and an appropriate distribution of the affiliations within the model. This choice was also made to have a reasonable computational time. The number of agents is directly related to the time it takes to run the model once.

The parameters that are considered for the exploration are given as follows:

1. For the backbone:
   (a) The belief hierarchy profile: for each affiliation a certain profile is designed. For the normal case, this profile is random. For a real model, the belief hierarchy would require modeller input using the belief of real agents collected through surveys, interviews or other means of identifying common political beliefs of different segments of the population, political parties, or particular policy makers and other actors in the policy network. For the exploration, three cases are considered. First every issue aim and causal relation is set at 1, for the second case, they are set to -1 and for the third case to 0.
   (b) The affiliation weight: these weights define the impact that agents of different affiliation have on one another. The weights are varied between 0 and 1 according to varied combinations. The aim here is to see what impact a change of weight has on the dynamics in the model and on the policy learning overall compared to the base case scenario.
   (c) The affiliation distribution: these distribution define what representation each of the electorate will have. This has an impact on the resources assigned to each of the agents depending on their affiliations. The distribution of the affiliation is changed such that in one case, all affiliations have the same impact but in another case, only two have a lot of impact. The aim is to display the impact of resources on the policy learning and ultimately the agenda chosen by the policy makers.
   (d) The electorate influence coefficient: this coefficient defines the amount of change in the aim of the policy makers for each tick due to their respective electorate. This coefficient is by default set to 0.001. To see whether the influence is working as intended and if these values have unexpected consequences, the coefficient

will be set to 0 and to 1 in different sets of simulation.

2. For the backbone +:
   (a) The resources potency parameter: it affects the impact of actions. It is set to 1 and 100 to see what impact a lot of powerful action have on policy learning.
   (b) The resources weight action: this coefficient defines the amount of resources in percentage that an agent can spend for every action performed. It is set to 1 and 100 to see whether a lot of small actions lead to a different outcome that one action per agent per tick. Due to time constraint the value of 1 is not tested as it would take too much time to run (100 actions per actor would need to be performed for each tick).
   (c) The awareness decay coefficient: this coefficient defines at which speed the awareness decreases over time. It is set to 0 and 1 to observe the changes in the policy network dynamics and the impact on the other parts of the model if there is no link decay or a large amount of decay.
   (d) The conflict level coefficients: these coefficients defines the value assigned to the conflict The coefficients are all raised to 1 to see if what the impact of the conflict level is on the actions and the overall policy learning occurring in the model.
3. For the three streams:
   (a) The team creation threshold - gap: the gap required to created a team is set to 0 and 1.5 which are considered to be two extreme values which would show a constant creation of teams or no creation of teams at all.
   (b) The team creation threshold - state: the difference in states between agents is varied from 0.1 to 1.5 similarly to the change in the gap.
4. For the ACF:
   (a) The coalition formation threshold is set to 0.1 and 1.5 to check the impact of this threshold on the fragmentation of the political arenas in different coalitions.

Each exploration model is run for 250 ticks. This corresponds to about 9 years of simulation in the real world if one considers that 1 tick refers to 2 weeks. Each experiment is only repeated twice because of time constraints. Ultimately, to get a better understanding, it would be of interest to have more repetitions. This is especially important for the other experiments where one would like to get a statistically representative output set.

## 6.5. The Base Case

After the exploration, experiments can be run with the different models. For each experiment a set of inputs must be chosen. The parameters considered are the similar to the ones shown for the exploration. For each of these parameters, an acceptable range is found. For the belief hierarchy three profiles are proposed. For each parameter, ten runs where considered with three repetition each. To have a statistically representative sample, the Latin Hypercube Sampling[1] was used to obtain which values to choose. Normally, experiments would see the variation of several parameter at once. However, it was assumed that because of the number of parameters and their relatively low impact on the results, such experiment design would lead to mixed outputs which would be hard to understand or explain. In the future, it would be advised to increase the number of repetition per run while varying sev-

[1] https://cran.r-project.org/web/packages/lhs/lhs.pdf

eral parameters at a time.

The input sets used are shown in the following list per model:

1. For the backbone model:
    (a) The belief aims (three profiles):
        i. Profile 1:
            A. Affiliation 0: Large values for the issues, large values for the causal relations.
            B. Affiliation 1: Exact opposite of affiliation 1
            C. Affiliation 2: Low values for the issues, low values for the causal relations
        ii. Profile 2:
            A. Affiliation 0: Low values for the issues, large values for the causal relations.
            B. Affiliation 1: Exact opposite of affiliation 1
            C. Affiliation 2: Low values for the issues, low values for the causal relations
        iii. Profile 3:
            A. Affiliation 0: Large values for the issues, large values for the causal relations.
            B. Affiliation 1: Exact opposite of affiliation 1
            C. Affiliation 2: Low values for the issues, large values for the causal relations
    (b) Affiliation weight 1-3: Interval 0.8-0.9
    (c) Affiliation 1: Interval 1%-50%
    (d) Electorate influence on the policy makers: Interval 0.001-0.010
2. For the backbone+ model, use what is already being used for the backbone model plus:
    (a) Resources potency parameter: Interval 1-10
    (b) Resources weight action: Interval 0.05-0.20
    (c) Awareness decay coefficient: Interval: 0.01-0.10
    (d) Conflict level (average one): Interval 0.8-0.9
3. For the three streams model, use what is already being used for the backbone+ model plus:
    (a) Team creation thresholds:
        i. Gap in belief: Interval 0.6-1.0
        ii. Closeness of problem: Interval 0.2-0.7
        iii. Closeness of policy: Interval 0.2-0.7
4. For the ACF model, use what is already being used for the backbone+ model plus:
    (a) Coalition formation threshold: 0.15-0.55

Throughout all of the experiments, during the policy formulation for all models and the agenda setting for the three streams model, the agents can select an instrument or a policy. These instruments and policies are specified by the modeller. For the backbone, backbone+ and the ACF models, the instruments do not vary throughout the runs. They remain as specified by the modeller. For the three streams theory, both the policies and instruments are influenceable by the agents. They are set up in a belief hierarchy like structure. Only the initial beliefs of the agents on these policies and instruments have to be specified by the modeller. The partial belief of the agents for the policy and instrument hierarchy are obtained as explained previously.

The base case experiment is simulated without any external events. It is used as a first look at the results from the model for varying parameters. Each simulation is run for 500 ticks which is also the case for the subsequent experiments.

## 6.6. Experiments

Besides the base case experiment, two additional experiments are performed. Both introduce external events into the simulations. They are explained below.

### 6.6.1. Experiment 1

The first experiment introduces an external event into the simulation. Then, because of time but also due to the results obtained for the base case experiment, only the belief profiles of the agents are varied. The other parameters are kept constant. The aim here is more to observe the impact of the external event and not the impact of varying parameters which can be observed in the base case experiment.

For experiment 1, the external event used is a switch of the causal relation linking the principle beliefs and the policy core beliefs. All causal relations, for all agents, see their sign changed. This is a way to simulate a complete shift in the agent's beliefs on how the world works. This external event is implemented at tick 200, long after what can be seen as the warmup time for the models.

### 6.6.2. Experiment 2

The second experiment follows the model of the first. The same external event is introduced but in a different way. In this case, the causal relations are only switched for the policy makers. The aim of this experiment is then to see what effect this has on the other agents and on the overall models.//

An infinite number of experiments can be performed. It is for the modeller to design what external event is desired according to the case study selected. External events can also be designed to trigger specific parts of the policy emergence model or the world model. These external events can be used to better understand the model and its complexity. It is in this mind set that the two experiments presented are used.

## 6.7. Limitations

There are several limitations to the approach provided in this chapter. The first one relates to the exogenous parameters. The list of parameters that can be changed is extensive. The modeller has access to a large set of parameters that can affect all aspects of the model in small or large ways. These parameters can affect the strategy of agents but also the number of agents and s/he can decide to have each agent with a different belief hierarchy. This means that an impossible number of experiments can be run with the model. It is therefore important for the modeller to focus on a specific aspect and try to maintain most of the parameters constant so as to be better able to explain the behaviours observed. This could also be a risk as the parameters left unchanged could be the ones responsible for specific behaviours. To address such issue, a full study of all parameters is advised to see which ones are the most important. This is beyond the scope of the present work due to time constraints.

Considering the number of endogenous parameters, it is also important to note that the modeller cannot record all of these parameters. The amount of data produced by the model is tremendous. Selecting the full belief hierarchy as an output can lead to output files ranging from dozens of gigabytes to several hundred per run. This is greatly affected by the number of agents chosen in the model but also the size of the original structure of the belief hierarchy. This problem becomes even more acute when considering the three streams model where the policy and instrument beliefs hierarchies can also be recorded. Ultimately, the modeller has the possibility to also record every actions that are performed by the agents. This would help in tracking what is happening in the model but would further increase the amount of output data. It is therefore important for the modeller to appropriately consider the variables of interest or to focus on the belief hierarchies of specific actors. For example, by tracing the belief hierarchies of just the electorate it is possible to see how public opinion changes based on different group identifications/affiliations. Furthermore, if a mistake is made and a parameter forgotten, re-running all experiments would take a significant amount of time. The choice of the saved parameters must therefore be carefully throught through.

# 7

# Results and Analysis

This chapter presents the results of the experiments that were detailed in the previous chapter. Accompanying the results are analyses of these outputs reflecting on the choices made earlier on in this report. The chapter starts with an introduction on what data is being looked at within this chapter in Section 7.1. It is followed by general remarks on the overall results in Section 7.2. The exploration results are then presented in Section 7.3 looking at whether issues arose when using large values for the different parameters. Remarks are then made about the three streams results in general in Section 7.4 and the results obtained from the ACF in Section 7.5. These remarks reflect on whether the presented model follow the two theories' main assumptions and display the expected behaviours. Then this chapter goes over the results obtained for the different experiments in particular. Section 7.6 looks into the base case results and whether the results reflect the expectation from the assumptions made during the formalisation. Section 7.8 and Section 7.9 look into the first and second experiment respectively. Section 7.10 concludes this chapter with some summarised remarks about the results obtained overall.

## 7.1. Results Presentation

The amount of data that can be obtained from the model is sizeable. Not all the data was however saved and exported. The data that is used and presented here remains considerable. It is therefore not possible to look at all the results within this report. It is however possible to get an understanding of the trends that are occurring in the different simulations and attempt to better explain the effects of the assumptions made to operationalise the different policy making theories.

For each model, a series of outputs are obtained. These outputs are separated in files related to the model, the agents, the coalitions, the teams and the electorate. To gain a better initial understanding of the outputs and the trends in the results, several python files were written. These are able to read and produce graphs automatically from these outputs files. However, considering the number of runs (more than 250 for the base case experiment alone), the number of models used (four), the number of agents (31), and the amount of parameters considered as outputs (more than forty including the belief hierarchy), a large amount of graphs can be produced. To limit this, graphs were only plotted for one set of experiment at a time (thirty runs) for three agents of the same type. This limits the amount

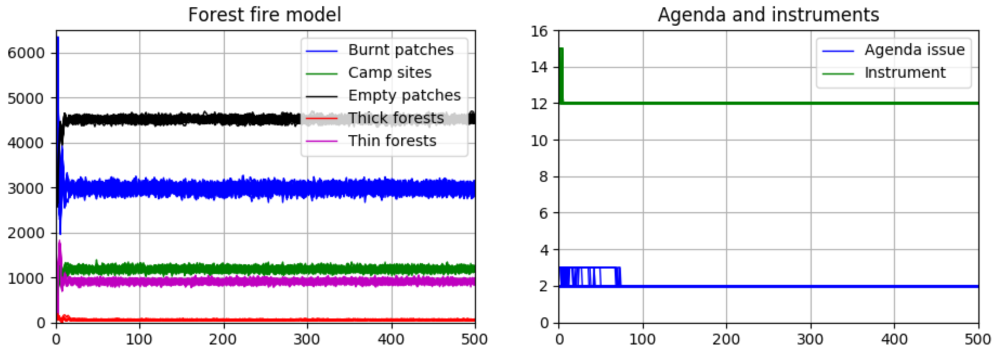


Figure 7.1: On the left, results from the forest-fire model showing the number of cells in the different states for 10 runs with three repetition each for the base case. On the right, results showing the choice of issue on the agenda and policy instruments chosen. These results are presented for the backbone.

of lines present in any one graph. The number of graphs is then related to the number of output parameters considered, most of which constitute the belief hierarchy.

These graphs were used for a broad exploration of the results. For the purposes of this report, graphs were sometimes tailored to show different types of agents together to illustrate the analyses and discussions. Graphs were also produced for the model results (agenda and policy instrument selected), the policy network evolution, and the teams and coalitions evolution.

## 7.2. The General Results

The aim of this section is to look at the forest fire model results and compare them to the policy instruments and agenda that are selected by the agents throughout the simulations. For each simulation, the different patch states were recorded for every ticks. From these results, it is possible to see their evolution over time. The agenda was also recorded for each simulation along with the instrument, if one was selected. These results are shown for a set of ten runs with three repetition each in Figure 7.1. The results shown are from a backbone simulation. This is the simplest model possible which allows for a better understanding of the dynamics and the connection between the forest fire model and the policy emergence model.

The first part of the graph shows the warmup of the model. This is the part just after the start where the patches number have yet to stabilise. After that, it is possible to see a very stable model. On the right side, the agenda selected and the instrument implemented are shown. From these results, it is possible to say that the safety is of concern for the agents, but after a short while, the agents are most concerned about tourism. This is constant throughout the model after tick 50. Similarly, the policy instrument that is chosen by the agents is initially policy instrument 15 but is then followed by policy instrument 12. Policy instrument 15 has a negative impact on the camp sites and a positive impact on the amount of firefighters. Policy instrument 12 has a small negative impact on the camp sites, a mild positive impact on the new forests, a small positive impact on the monitoring, a large negative impact on firefighters and a mild negative impact on the fire prevention. The details are shown in Table C.1.

One can see that the implementation of these policies seems to have very little impact on the forest fires. Throughout the 500 tick simulation, the forest fires remain very stable for all patches. This behaviour can be explained by several issues:

1. The policy instruments are inadequate: the agents can only select an instrument that is proposed to them. They cannot make up a new instrument or combine the different instruments proposed into a new one. This is because the instruments are specified by the modeller initially and remain as such throughout the simulation. The instrument chosen by the agents might be an inadequate instrument but, nonetheless, remain the best instrument they can implement. Being inadequate, this instrument would only have a limited, if not null, impact on the model as can be seen from the results.
2. The causal relation of the agents are incorrect: this would make the agents within the model make false assumptions on how the world works. This would explain why they keep choosing one policy instrument while they can clearly see that it has no effect on the forest fires. Because the agents are wired as they are from the beginning, they cannot see that they are 'thinking' wrong. Only an external push on their beliefs into the correct direction would then put them on the right path to adopt appropriate instruments. This theory is however implausible because of the initial setup of the agents. Three groups of agents, based on affiliation, are initialised. They all have relatively different beliefs. This would therefore suggest that out of all three possibilities, one agent group would have appropriate causal relation. That agent, being in the right, would then influence other agents into thinking as him/her. This does not happen.
3. The implementation of the world model and its integration with the policy emergence is incorrect: the calculation of the states is incorrect and the application of the instruments is flawed. A key point when linking the world model to the policy emergence model is the calculation of the states. This process is performed before the policy emergence model based on equations provided by the modeller. It is important to understand that these states, in most cases, do not relate directly to parameters that are present in the world model. For example, in the forest fire model, the tourism state cannot be obtained directly from the forest fire model, instead it is derived from other parameters. This equation is crucial and, if incorrect, can provide the wrong states to the agents. This then leads to flawed agent actions.
   Furthermore, the modeller must map the obtained values onto an interval of -1 to 1 as shown in the formalisation. This can cause issues when the parameter considered has no real maximum or minimum. It is then up to the modeller to decide what a 1 and a -1 means within the context of the model selected. In the case of the forest fire model, it was fairly easy to assess the states for the secondary issues. This is because all of these issues relate to the number of patches present in the model. 100% of the tiles being thick forest therefore lead to a thick forest state of 1. The opposite is then true for 0% of thick forest leading to a score of -1 of thick forests. However, for the issues that are situated on the other layers of the belief hierarchy, the equations were made up and the decision that lead to choosing the maximum associated to 1 and the minimum associated to -1 were most likely inadequate. The equations used are shown in Appendix C.
   This brings up another issue with such an approach and this applies specifically to this belief hierarchy. The aims of the secondary issues of the agents present in the

model would have to add up to 1 to be compatible. If they do not add up to one, it would effectively mean that an agent would want 100% of the patches being thick forests and, at the same time, 100% of the patches being empty patches. This introduces a conflict within the agent's belief system, Note that this is not necessarily wrong, as agents that do not understand how the world works might wrongly assume that this is possible. Within the forest fire model, and the agent initialisation used here, the beliefs were chosen more or less randomly which would indeed lead to these conflicts.
Overall, it seems that the bridge between the world model and the policy emergence model were not addressed appropriately. This lead to the results presented for the agenda and the policy instruments. However, this has almost no impact on the policy emergence model, and the mechanics used there. This will be detailed further in this chapter.

## 7.3. The exploration results

As presented in the previous chapter, the exploration of the results is related to extreme value testing experiments. The aim here is to see how the model reacts to extreme values of the inputs. This part can be both seen as a verification of the model and a way to better understand what effects some of the conceptualisation assumption have had on the results.

Looking through the results, the exploration of the model using large values for the different parameters does not point to issues with the model. The outputs show that the behaviours are within the accepted and expected thresholds. For conciseness, the plots are not shown within this report. The four different models do not exhibit any unexpected outcomes beyond issues with the world models. The change in the different parameters is explained for the experiments presented later on. This approach is preferred as the results obtained here are not representative. The exploration was only meant to see how the model would behave using extreme values.

## 7.4. The Three Streams Theory

The three streams theory is one of the most qualitative theory that is being used within this report. This means that it is hard to link outputs of the model to the theory concepts. The two main concepts that are addressed within the theory are the policy window and the three streams. However both these concepts are not outcomes of the model itself but rather they are assumptions that are used to build the model. The policy window opens once the agenda is created which happens every tick. A policy window is then considered to be successful if an instrument is implemented. This is often the case in the model, as the previous results show for the general model. On the other hand, the concept of stream is not addressed as stream but is considered through the policy hierarchy, the belief hierarchy and the policy network. This is directly stemming from the conceptualisation an formalisation and not linked to any of the outputs from the model.

Additional concepts that are attached or used to formalise the theory are present in the outputs. These are concepts such as the teams or the inherent policy learning that is a result of the approach taken. These concepts and the results regarding them are present in a subsequent section. They are not considered to be part of the three streams theory but instead to the policy entrepreneurship model.

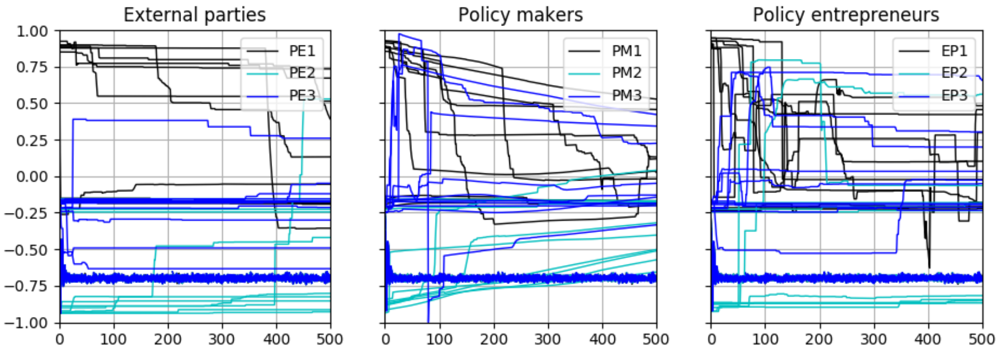


Figure 7.2: Representation of the evolution of the first secondary belief for three external parties, three policy makers and three policy entrepreneurs. For each actor, ten simulation with three repetition each are displayed. In full lines, the aims of the agents while in dashed lines, the states.

# 7.5. The Advocacy Coalition Framework

For the advocacy coalition framework, several assumptions made in the theory can be directly observed within the outputs. These relate to the policy learning of the agents, to the speed at which the different beliefs are changing within the belief hierarchy and to the coalition dynamics.

## 7.5.1. Policy learning

Policy learning can be observed throughout the simulation outputs. Figure 7.2 shows one such outputs for three external parties, three policy makers and three policy entrepreneurs. The policy learning occurs for issue states, issue aims or causal relations that the agents are interacting about. Once can see from these plots that such interaction occur in steps, hence the semi-continuous aspects of the curves. The beliefs of the agents can go up and down throughout a simulation. This is dependent on the actions that are performed on them and by which agent they are performed. As expected from the conceptualisation and formalisation, depending on the political affiliation, the resources and the conflict level, the impact of the actions will vary.

Throughout the results observed, most actions found to be occurring are actions related to the issue aims for the agents or the causal relations. For most simulations, at least two issues or causal relations are never influenced by agents. This suggests that these issues or causal relation were always considered irrelevant by all agents. Similarly, it seems that throughout all simulations, and this cannot be shown in plots here as it would involve thousands of graphs, the state values of the agents are very rarely influenced. However, within the exploration results, evidence showed that the states were modified throughout the different simulation. This suggests that for the experiment here, the states actions were consistently graded lower than the other possible actions.

Furthermore, and this is a direct result of the common core, policy learning can be observed in all models, and more specifically in the backbone+, the three streams and the ACF models. The backbone only displays policy learning for the policy makers due to electorate influence but no active actions are performed within that model. Such policy learning results are shown for three policy makers in Figure 7.3. One can see that policy learning occurs for all models but that the final outcome is different between the four models.

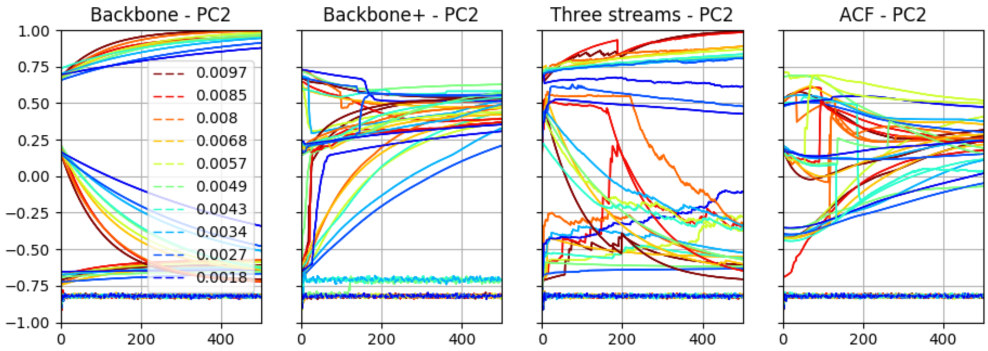


Figure 7.3: Comparison of results for the four models for three policy makers of different political affiliation for varying values of the electorate influence for the second policy core beliefs. This graph is constituted of 10 runs with three iteration each.

## 7.5.2. Belief hierarchy evolution

The evolution of the different layers in the belief hierarchy is different than what the theory would suggest. This is however not totally linked to an emergent phenomenon. The speed at which the beliefs in each of the layers will be changing is only related to the amount of resources. Considering the resources are the same in all the steps of the process used in this simulation, all changes have the same magnitude. Furthermore, the current model does not allow for any active actions on the principle core beliefs of the agents. These beliefs therefore remain static throughout the simulations.

Several solutions could be used to address such issues to better reflect the theory presented in the ACF. The first one would be to alter the number of steps that are used in the process being simulated. One such solution would be to perform the agenda setting step and then more than one policy formulation step before the world is run for each tick. This would allow for more modification of the secondary beliefs compared to the changes being effected on the principle core beliefs. A similar solution that would have the same effect would be to keep the number of steps in the process but to increase the amount of resources provided to agents in the policy formulation step compared to the agenda setting step. This would allow for more actions, and ultimately more belief evolution for the secondary beliefs. A third similar solution would be to increase the potency of the resources in the policy formulation compared to the agenda setting. This solution is mentioned as it is similar to the previous ones and because a potency parameter is already present within the Python code used for the simulation. It would therefore be simple to implement.

To deal with changes in the principle core beliefs, additional actions would have to be devised by researchers. The main issue with such changes is that principle core beliefs are the basis for most of the belief hierarchy. It affects the choices on all the other layers of the hierarchy. Changes in these beliefs are therefore crucial and any new action devised would need to be well justified. Currently principle core beliefs are initialised by the modeller and stay as such throughout all simulations. Finally, and most importantly, the new mechanic should show a very slow change in these beliefs. This is crucial for the overall behaviour of the model and to remain close to what the ACF assumes.

### 7.5.3. Coalition dynamics

One of the aspects that the ACF describes is the overall dynamics of the coalitions. It assumes that coalitions are long lasting entities based on deeply entrenched beliefs. It is possible to study whether such behaviours are present within the ACF model formalised and simulated. Figure 7.4 presents the dynamics of coalition in one of the experiments. In all six plots, the red corresponds to the coalitions in the agenda setting process and the black corresponds to the coalitions in the policy formulation process.

The first graphs on the left present the number of coalitions. A striking difference quickly appears between the number of coalitions present in the two processes. The number is low for the agenda setting while it is fairly high, by the theory's own standards, for the number in the policy formulation. This can be explained by the initialisation method that is used for the agents partial beliefs. At the beginning of a run, all agents are aware of all other agent's principle beliefs with a small margin of error. Nonetheless they have a certain amount of understanding of each other's beliefs. This means that, when creating coalitions in the agenda setting phase, agents can make informed choices and create a small appropriate number of coalitions. This is not the case in the agenda setting. For the policy formulation, the agents create coalitions based on their partial knowledge of the policy core beliefs of other agents. However they only have very little knowledge of the other agent's partial beliefs (they are initialised with an almost random number). This leads to a fragmentation of the coalitions and such a high number of coalition.

Surprisingly, the number of coalitions increases over time while common logic would suggest that this number should go down. This behaviour could be explained by a polarisation of the agents on their policy core beliefs along with a fragmentation of the policy network. This would mean that agents that start coalitions have a small network along with extreme beliefs leading to smaller coalitions overall and therefore a higher number of coalitions. The polarisation can be observed in the results to a certain extent justifying the results obtained. Furthermore, the decrease in the policy network of the agents can also be observed in the associated results.

The second plots show the number of agents in a coalition. A similar behaviour can be seen as in the first plots. The number of agents in coalitions for the agenda setting is consistent with the observations made previously. Similarly, not all agents are placed in coalitions as shown in black during the policy formulation. This is because of the lack of partial knowledge from one agent to another.

Finally, the third plots show the resources of each coalition. This can be seen as a proxy for the average cohesion of coalitions as the resources are dependent on the belonging level. The higher amount of resources is related to the fact that the members of a coalition feel strongly part of the coalition, they have similar beliefs. Similar results can be observed as was mentioned previously. The important point is the fact that the resources of coalitions tend to climb for the policy formulation coalitions as the simulation runs and as agents in the model gain a better understanding of each other's beliefs. This shows that, although they are polarised, the coalitions are created with agents that share similar beliefs making them more effective in their actions.

What can also be seen is that in the agenda setting, the resources start decreasing after tick 300 before stabilising between 26 and 28. The main reason behind this lowering is related to the change in principle beliefs of the policy makers. They are influenced by the electorates on their principle core beliefs. And, following the formalisation, the other

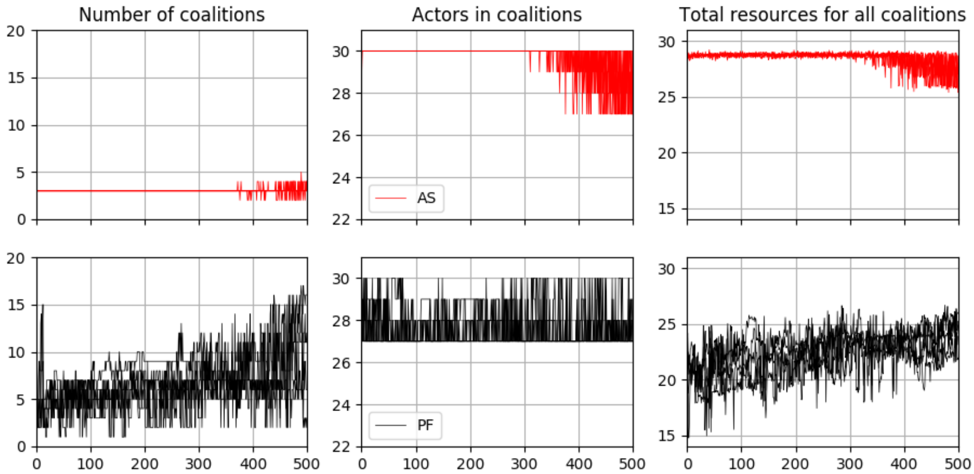


Figure 7.4: Graph showing the coalition dynamics in both the agenda setting and policy formulation processes for the ten runs with 3 repetition each when varying the affiliation distribution of the policy makers.

agents within the models cannot interact on that belief level with one another. This means that they cannot gather more information about each other's beliefs. This leads to this decrease in coherence within the teams. Ultimately, if the model were to run forever, this could become a problem as the partial knowledge of the agents would not match with the actual beliefs and this could not be updated. The addition of actions at the principle belief could help fix this issue and lead to a sustained coherence in the coalitions.

## 7.6. General analysis - Base case

This section presents different observations made on the base case. These relate to the different mechanisms considered within the conceptualisation and the formalisation. They were tested through a parameter sweep in the base case experiments and these results are presented here. These results are only a preliminary look and should be supplemented by more detailed studies in the future.

### 7.6.1. The four models comparison

Before diving into the separate parameter analysis, it is important to observe the overall results and compare the results between the different models. These results show that they can be radically different depending on the experiment considered. Overall two parts can be differentiated: the policy outcome and the policy learning or individual agent's beliefs outcome.

Regarding the policy outcomes, the results are fairly similar across the models and the simulations. The agenda is consistently similar and so is the instrument being selected for implementation by the agents. This commonality is suspect and considered to be incorrect. The reasons are the same as the one presented before. They are related to a faulty approach in how the states are calculated and transmitted to the agents along with a faulty implementation of the instruments.

Regarding the policy learning, the results are strikingly different. Results from the backbone+ tend to be smoother with a more constant, and less urgent, policy learning in each

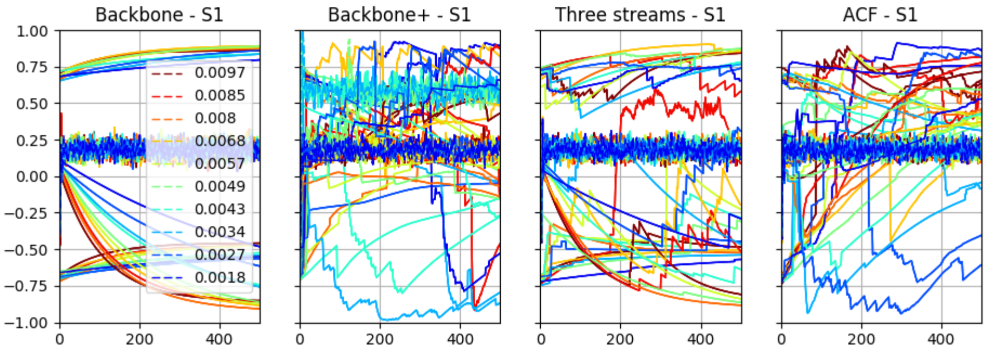


Figure 7.5: Graph showing variations of the electorate influence on the policy makers. The results here show three policy makers for their first secondary belief for ten simulation with three reptition each.

of the beliefs. The results for the three streams and advocacy coalition models are much more chaotic with large changes in the beliefs of the agents at any one time. Finally, as can be seen in Figure 7.3, the results from the different models do not lead to the same final beliefs for the different agents. On the contrary, the belief outcomes can be very different. The main expected reason behind such different outcomes can be explained because of the impact of the teams and the coalitions. These groups of agents can perform large influencing actions compared to individual agent actions. This leads to fast and large changes in the agents beliefs making the model more volatile.

The modeller could tune this part of the model such that the policy learning be slower. The different in action power being coalitions and teams will however remain. If the policy learning is happening too quickly, the modeller could turn down the potency parameter for the actions for all agents. The opposite is also true for too slow policy learning. The policy learning rate should be established on case study basis by the modeller after a certain amount of testing and tuning of the model.

### 7.6.2. The electorate influence

The main impact of the electorate influence is seen on the policy makers as would be expected. Such behaviour can be observed in Figure 7.5 and Figure 7.6. The speed at which the policy maker's aim are influenced is dependent on the coefficient selected by the modeller. Figure 7.5 shows that the electorate influence is however not dominant when actions are being performed. For the backbone where no actions are performed by the agents, the beliefs will follow a smooth curve due to this electorate influence. For all other three models, the agent actions have a large disruptive effect on that smooth progression. However, after an action has been performed, the agent's beliefs will go back to tending to their respective electorate's belief through the electorate influence. The beliefs therefore never remain stable for the aim of the issues of the policy makers. For the external parties and the policy entrepreneurs, this effect is of course completely inexistent. The only effect that can be observed there is the influence of the policy makers that were influenced by the electorate previously. The electorates therefore have a far reaching but diminishing influence.

The electorate influence coefficient that drives the behaviour of the electorate influence is an important parameter. There are two ways in which this coefficient could be used in future case studies. If the modeller would like to tune his/her model, then s/he could try different coefficient values until the results match what is observed in the real world. This can also be done by setting a profile over time of the value of the coefficient, as it is unlikely to remain constant throughout twenty years or more. The second option for a modeller would be to vary the coefficient to see its effect on the different agents. The aim here is not to see the impact on the policy makers, but instead to see how this affects the other agents in the model. This is a difficult behaviour to observe because of the number of actions in the simulation. However, it can have a driving effect on the beliefs of the external parties and the policy entrepreneurs. This, of course, results from the influence of the policy makers on these agents. Such influence can also cross political affiliation, which is not the case for the electorate influence.

One experiment that has not been tested here, but that could be of interest, would be to look at the effect on a varying electorate influence in the case of an unbalanced distribution of resources between political affiliation. This means that one political affiliation concentrates most of the resources. The conceptualisation would suggest that, in such a case, this would lead all electorates to be influenced by the most influential electorate. This would happen through the loop of influence from electorate to policy makers to external parties to electorate. It would be interesting to compare this with case studies and see if what is conceptualised in this report matches what can be seen in case studies. This could help validate the assumptions that were made to formalise the policy making theories but also validate the theories themselves.

### 7.6.3. Impact of the external parties on the electorate

The external parties can perform influencing action on the electorate's aims. One output that shows such actions is shown in Figure 7.6. The external parties are indeed performing actions on the electorates in some cases. The results shown in that figure are unambiguous. They clearly show the electorate's beliefs changing due to the external parties influence. This is however not the case for a lot of other outputs not shown here for conciseness. In these results, the influence of the external parties is oscillating around an almost constant point leaving the beliefs of the electorate fairly stable. The oscillating pattern can be attributed to different external parties having different political affiliation being as powerful. This ultimately leads to a 'fight' between these external parties to influence certain electorates on a specific issue leading to the various beliefs going up and down. In other cases, the aims of the electorate will tend to join one another leading to a common view on certain issues. This is due to the influence of some of the external parties being stronger than other external parties. It will pull the beliefs of the electorates towards their own beliefs despite these electorates not sharing any political affiliation with the external parties influencing them.

Figure 7.6 also shows that such impact on the electorate has, in turn, an impact on the policy makers. On the right side, one can observe the associated aim beliefs of the policy makers. For the times where the electorate is heavily influenced, the policy makers beliefs are also affected as can be seen for some of the simulation for the first and second policy makers towards the end of the simulation. This is currently the only way principle beliefs can be influenced in this model.

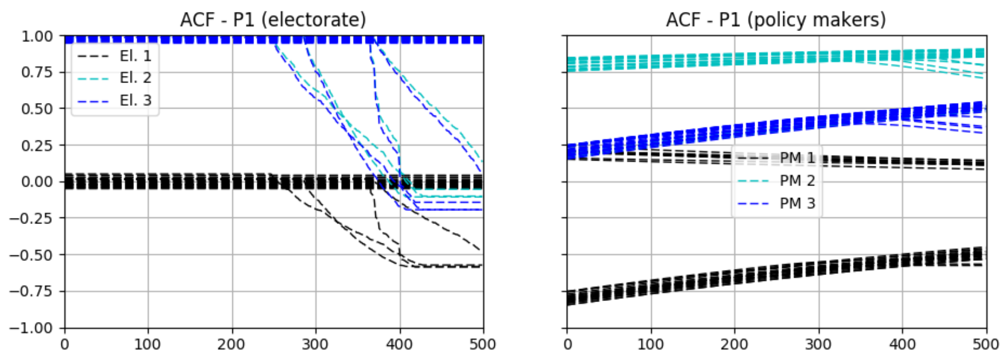


Figure 7.6: Graph showing the beliefs of the electorates (left) and three policy makers (right) principle core beliefs for the ACF for ten simulations with three iteration each.

### 7.6.4. Change in the belief profiles

Different belief profiles were tested. These belief profiles changed the goals for the issues of the agents depending on their political affiliations. The results show that the initial selection of the belief profile for these agents has a large impact on the policy learning. When looking at these results and the evolution of the beliefs of the agents, it is important to take into account the electorates' beliefs. The agents' beliefs will tend to the beliefs of their respective electorates due to the influence of the electorate on the policy makers. This is most acute for the policy makers as they are directly influenced. The rest of the results only show that depending on the initial beliefs, the point to which the belief of the different agents converge will be different. This can be attributed to a mix of political affiliation (related to resources) and difference between agent's beliefs. The beliefs will end up close to the agents with more resources (having a strong political affiliation).

### 7.6.5. Resources potency

The resource potency parameter increases the effect of the resources when agents perform influencing actions on other agents. The effect of this potency parameter is difficult to assess throughout the results. This is due to the fact that the actions performed and their impact are not recorded as outputs of the model. The reason behind this decision was mostly related to the large the amount of data expected. Looking at the results of varying potency parameter values, it is difficult to draw any conclusions from the effect of using a potency ten times higher than usual. The impact of the actions, as seen in the various graphs plotted, seem to be the same for a potency of one or of ten.

The main reason behind such results is that agents can each perform a certain number of actions. With a higher potency, the agents' action impact will increase allowing them to perform different actions on other agents. With a lower potency, the agents' action impact will decrease and they will have to keep performing the same action on the same agent to obtain the same outcome. This should be seen through the speed of the policy learning. However it is hard to assess this speed as it is distributed on different beliefs and causal relations. Additionally, as the actions performed are not tracked, whether such behaviour happen cannot be strictly verified. One way to assess this in the future, without having to track the actions of the agents would be to limit the actions of the agents to one (they spend all resources at once). This would potentially allow the modeller to see more eas-

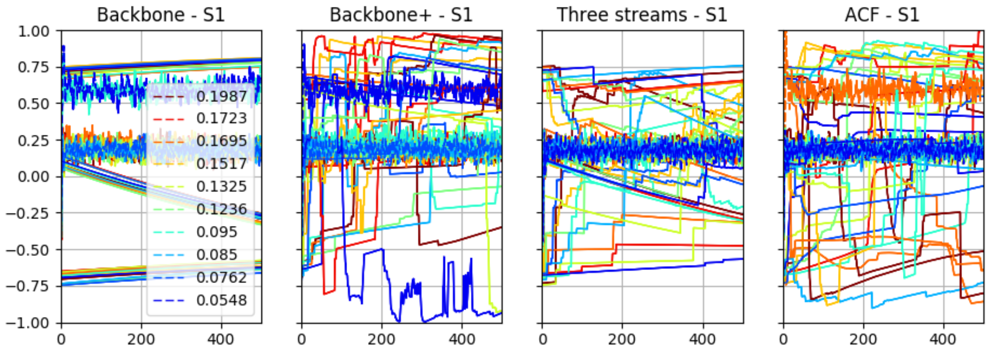


Figure 7.7: Representation of the first secondary belief for three policy makers for the four models. Each simulation represents three repetition for varying resources weights.

ily if the simulations where the potency value is higher has faster policy learning than the simulations where the potency value is low.

### 7.6.6. Affiliation weights

Similar conclusions can be drawn from the affiliation weight experiments. As shown in Figure 7.7, it is difficult to come to a conclusion on the effectiveness of this parameter. Such graphs can be observed for all agents for all beliefs for all models simulated. Without recording which actions is performed by whom on which agent and compare it to the actions that were proposed, it is hard to draw serious observations from these results. One can observe that for the causal relations, the agents will always have converging beliefs. And these beliefs converge towards one dominant agent. This is the case for all experiments and not only for experiments where the affiliation weights are changed.

One way to test the weight changes would be to record the number of actions performed by each agents and their overall impact. Comparing such actions between the different agents could help understand the effect of this parameter and see whether agents that are performing more actions but with less impact or less actions but with more impact have the most influence within the model.

### 7.6.7. Affiliation distribution

For the affiliation distribution, the same as previously mentioned can be observed in the results. One would expect from the results that agents with a stronger affiliation will dominate other agents and the beliefs will be impacted both faster and will lead to different outcomes. This is not clearly seen within the results and it varies from model to model. In most cases, the affiliation power does not seem to affect the results, it does not lead to a change of speed at which the beliefs are affected. To better understand whether this mechanism works appropriately would require different or additional outputs. It would be important to look, as mentioned earlier on, at the total impact that an agent has for each round of influence. More detailed data would also lead to a better understanding on which issue the agent will influence and which agent the focus will be placed on.

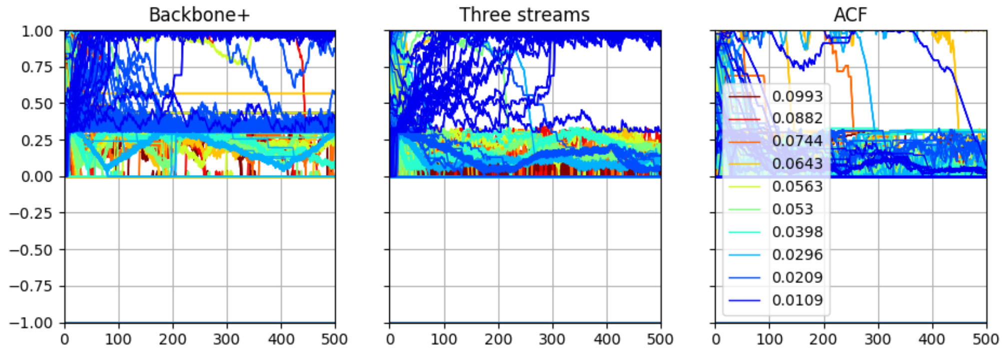


Figure 7.8: Representation of the trust in the awareness of agent 14 (a policy entrepreneur) for varying awareness decay values.

### 7.6.8. Awareness decay

The awareness and the agent's network was looked into through the variation of the awareness decay parameter. This parameter defines at which rate the awareness of the agents deteriorate over time when no actions are being performed. Some of these results are shown in Figure 7.8 for a policy entrepreneur. The plots show the evolution of the network of this policy entrepreneur within the different models. The backbone theory is not considered as the network there is not used. The colours represent the varying awareness decay values.

From the outset, it is possible to see that the lowest value of decay dominates the chart with the highest awareness levels. This is the case for all three theories considered. This suggests two things. The first is that the awareness decay has a clear impact on the awareness levels of the different links. One can see that in the ACF, the blue lines decline at a slower rate that the other colours lined which have higher levels of awareness decay.

The second point is that this graph does show that the agent performed a lot of actions with other agents in the case of the low awareness decay. This highlights a self-reinforcing mechanism. The agent performs an influencing action on an agent with whom s/he has a high awareness level. This will help maintain that awareness level which means that the awareness will remain high increasing the likelihood of performing another influencing on that agent. Furthermore, the maintenance strategy also has an impact here. The maintenance strategy selected for all experiments is the second strategy. This was not varied for any of the experiments due to time constraints. In this strategy, the agent will maintain links that have a low awareness level and which connect agents that have similar beliefs. This can be clearly seen in the Figure 7.8 with a strong line emerging at an awareness level of 0.3.

An additional observation that can be made relates to the differences between the models and issues within the implementation of the conceptualisation and the conceptualisation itself. The implementation of the actions within teams and coalitions has an impact on the results shown here. Within coalitions, when a team leader implements an action, the awareness decay is not paused for any of the other agents that are part of the coalition. This has a degrading effect on the overall network as only individual agent actions lead to a pause in the decay of the awareness. Considering that a majority of the actions are performed at the coalition level, this explains why the awareness level of the network of the agent considered in the ACF is so depleted compared to the other two models. The same remark applies to the three streams and the teams. However, teams perform less actions

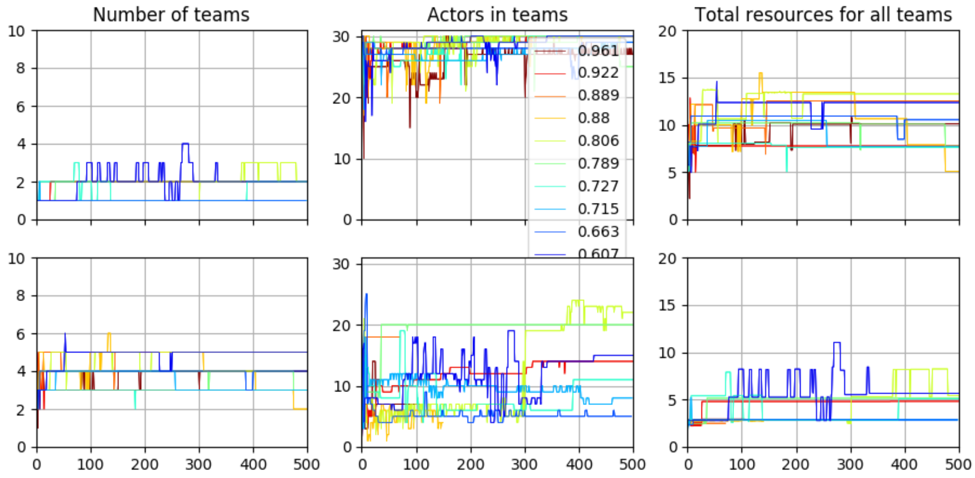


Figure 7.9: Representation of the teams for variation of the threshold for the creation of teams. The dotted lines represent the agenda setting step while the full lines are for the policy formulation step.

than the coalitions and less agents are present within teams. This therefore leads to a less depleted network. This issue should be addressed in subsequent work.

## 7.7. Team analysis

The analysis of the team results is similar to the one presented for the coalitions. Figure 7.9 displays the main results from this experiment. The graphs shows, similarly to the coalitions, the number of teams, the number of agents in the teams and the total resources for all teams.

Several comments can be made based on this figure. First, it is possible to see that there are more teams for the policy formulation than the agenda setting. This is opposite to coalitions. However, there seems to be more agents in teams in the agenda setting phase. This would suggest larger team during that phase compared to the teams in the policy formulation. This argument is supported by the fact that teams in the agenda setting process have more resources. This means that they are either closer or have more members or both.

Upon looking at the raw output files, some issues start to arise with the results. The teams linger for too long within each simulation. Some teams last as long as half the entire simulation which is neither the goal nor the function of teams. The teams behave more like coalitions than was aimed for in the conceptualisation where teams were conceived as temporary groups used to further the interests of certain agents. Additionally, teams seem to contain as many agents as coalitions, and sometimes even more. This is also not the original intention of the team concept.

Several solutions can be considered to remedy to these problems. They are present at different levels. At the lowest level, these problems could be due to a lack of tuning of the threshold used to constitute teams. If these thresholds are tightened, the teams might be smaller and could disband more often. Another issue might be related to the formalisation of the team concept itself. A new rule could be added which would make teams forcibly disband after a certain number of ticks or after an issue has been pushed onto the agenda or an instrument has been implemented. This could limit the duration of teams. Finally,

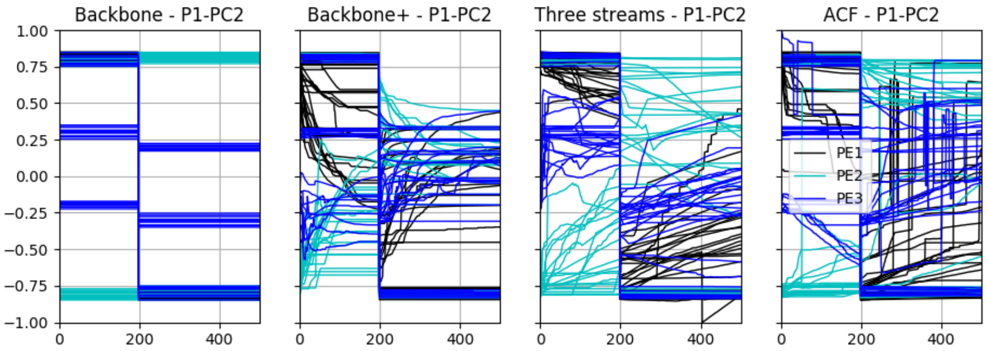


Figure 7.10: Representation of the causal relation between the first principle belief and the second policy core belief for three policy entrepreneurs for ten simulation repeated three times each.

issues related to the partial knowledge might also play a role in the creation of the teams as the creation of teams is based on this partial knowledge. Fixing the world simulation and the connection between the world simulation and the emergence model could also work to address the team continuity issue. Such a fix would lead to a larger variety of agendas and policy instruments which in turn would lead to agents changing their issue of interest more often leading to the disbanding of teams and their renewal with different agents. Finally, this also brings up the introduction of complex external event scenarios where external events occur on a regular basis. This could have a similar effect and could lead to more ephemeral teams.

## 7.8. Experiment 1 - Results

The first experiment consists of adding an external event that switches the signs of the causal relations situated between the principle and policy core beliefs of all agents. The aim is to see whether this has an impact on the agents present in the model, and ultimately on the agenda and policy instrument selected by the agents. The switch of this causal relation is akin to providing a new understanding to the agents on how the world works.

Figure 7.10 represents a small sample of the results obtained from the experiment. One can see from this graph the clear change in the causal relation related to the external event. What can be directly seen from this figure is that, in most cases, the trends remain constant for most of the simulations in most of the models but on the other side of the x axis due to the external event. The causal relation beliefs do not head back to where they were prior to the external event. This can be partly explained by the fact that all agents are influenced at once. As all their causal relation beliefs switch, the influence action they will perform will attempt to make other agents think the same way as they now do. This hypothesis is further tested within the second experiment presented in the next section where only the policy makers are affected by the external event.

The impact on the causal relations is not as clear. The impact on the issue beliefs of the agent is more unclear. There is no impact on the principle beliefs which is expected. The changes in the beliefs at the policy core level are hard to observe. In some cases, for some agents and for some issues, a spike can be seen at the point where the external event happens. Furthermore, some trends are cut by this external event. This suggest a change in the priorities of the agents and the start of a different influencing strategy based on their new understanding of the world. The same can also be said for the beliefs at the secondary level.

The external event has a cascading effect on the aims of the electorate through the external parties. It can be observed from the results that the electorate is clearly affected, although at a slow pace, by the change in the causal relations. This affects the aims of the electorates for their policy core beliefs. This is expected through the influence mechanisms that the external parties have. No impact can be seen on the principle and the secondary beliefs.

For the three streams theory, and regarding the teams, it is possible to observe a change after the external event occurs. In most simulation, the number of teams jumps before going back down. This is the same behaviour as the one observed at the beginning of the simulation. This suggest an intermediate warm up period due to a lack of partial knowledge from the agents. The agents initially perceive they can create teams because they think they share the same beliefs on the new items at the top of their preferences. However, after several ticks, they realise this is not the case once they have obtained enough partial knowledge. This is most pronounced in the agenda setting phase due to the fact that the causal relations changed have the most impact at the agenda setting level.

For the coalitions, in the ACF, no such observation can be performed. There is no change in the number of coalitions or the resources provided to coalitions for both the agenda setting and the policy formulation phases. This can be explained by the rigidity in the creation of the coalitions as theorised by the theory. Furthermore, the agents have a much larger understanding of the beliefs of other agents within the ACF because of the exchange of beliefs when they are part of the same coalition (which most agents are).

Perhaps the most important impact of the external event relates to its effect on the agenda and the policy instruments chosen by the policy makers at the end of each round. However, as explained previously, the results are flawed. The policy emergence is not affected by the chance in the causal relation. The agenda chosen by the policy makers along with the instruments implemented do not vary. No explanation can be provided on this beyond what was said in previous section. The issue here is to understand whether this is because of a lack of good policy instruments or it is because of a flaw in the connection between the two parts of the or both.

## 7.9. Experiment 2 - Results

The aim of this second experiment is to confirm some of the assumptions made to explain some of the behaviours in the first experiment. Here only the causal relations of the policy makers are changed. The aim would be to show that this has an impact on all the agents of the model, but much smaller than it was in the first experiment.

As expected, the results show that the policy learning resulting from the external event is much less pronounced than for the first experiment. Instead of seeing the causal relations of the different agents switch sign and converge to a point that is the same as the point they were converging to prior to the external event, they converge to a new point. This can be clearly seen in Figure 7.11. Most causal relations only slides just a little for the policy entrepreneurs and the external parties. This sliding is more or less pronounced depending on the causal relation considered. Furthermore, this behaviour can be observed for both types of causal relations. The effect is however smaller for causal relations linking secondary and policy core beliefs.

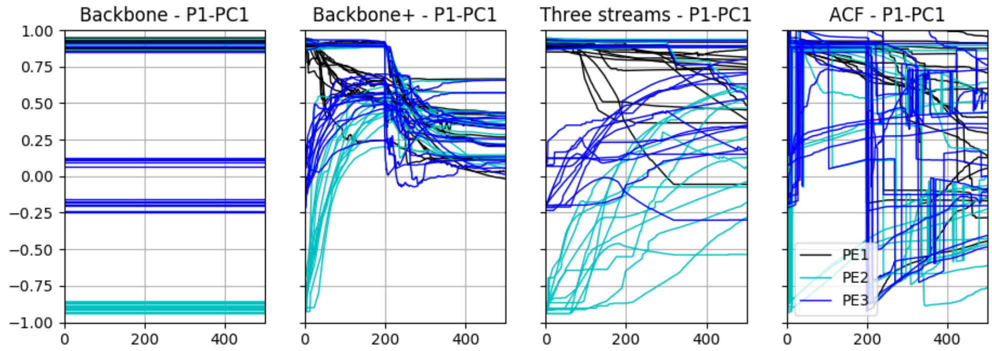


Figure 7.11: Representation of the causal relation between the first principle belief and the first policy core belief for three policy entrepreneurs for ten simulation repeated three times each.

The causal relations beliefs of the policy makers show a more pronounced change. This is first because of the external event that leads to a change in sign of the values. But then, the policy makers are influenced by the other agents, they therefore regain a large part of their beliefs compared to where they were before the external event. It is also during this time that the policy makers influence the policy entrepreneurs and the external parties leading to their own small change in beliefs. Finally in some cases, the causal relations of the policy makers go back to their original point of convergence despite the external event. This can be explained by other agents focusing on that specific causal relation and directly influencing the policy makers.

Contrarily to what was observed in the first experiment, the impact on the coalitions and teams is negligible or not observable. This is the case both for the agenda setting and the policy formulation. The impact on electorates' beliefs is also negligible. There is hardly any change in their beliefs. This is because the impact on the external parties is too small for them to also affect the external parties. Finally, no change in the agenda or the policy instruments implemented can be seen. Similarly to the first experiment, this can be due to the issues with the implementation of the forest fire model.

## 7.10. Conclusions

The results presented within this chapter provide a better understanding of the model built while signalling that this work is only an initial look at the overall model and its potential results. The results obtained for the exploration and the three experiments provided strong evidence that the key concepts of the three streams theory and advocacy coalitions can be observed. Policy learning can also be clearly seen throughout all of the results. However, it also showed some of the issues and limitations of the model. The two main ones relating to the amount of data required to study the model outputs along with the need for a strong and well designed connection between the world model and the policy emergence model.

# 8 Discussion and Conclusion

To conclude this work, it is important to reflect on the initial research question formulated in the introduction. It was given as: "How can the emergence of policies be simulated using policy process theories within an agent based framework?". The research sub-questions also helped established a direction for the research performed in this thesis. These questions are answered here and supplemented with additional discussions in Section 8.1. A general reflection on this thesis is then performed in Section 8.2. The main points that are considered to be further work are mentioned in Section 8.3. This report is finally concluded with the answer to the main research question in Section 8.4.

## 8.1. The Sub-questions

This section details the answers to the four research sub-questions that were formulated within the introduction to guide the work presented in this thesis.

***What conceptual model can be made which would cover the largest possible intersection of all the aforementioned policy making theories?***

A conceptual model was formed based on the four policy making theories considered within this thesis: the three streams theory, the feedback theory, the advocacy coalition framework and the diffusion theory. Due to the qualitative nature of these theories, a set of assumptions had to be made to conceptualise these theories within one common model with extensions.

The approach taken was to use in common concepts that are present in the different theories and that can be put in common, and then build an independent extension for each theory that can be activated, or not, based on research questions and approach. There are three main overarching concepts that can be considered for this: the belief system expressed in the advocacy coalition framework, the concept of iterative stages that is part of the policy emergence process in general and the actors actions that can be adapted from the three streams theory and the advocacy coalition framework.

One of the most important part of the common core of the model is the belief system. This belief system is adapted from the ACF as mentioned previously (Jenkins-Smith et al., 2014). This belief system is the belief system used by all of the actors within the model providing commonality between them. It is composed of a tiered hierarchy. The different tiers are filled with issues on which the agents can have beliefs. These beliefs are categories in aim and states which can be used to calculate the preference by the agents to select specific issues. The issues are also related to one another through the different tiers of the hierarchy. These are the causal relations which define the understanding of the actors on how issues influence each others. The aim with this hierarchy structure was to be provide each actor with a gap for each of the issues present in the system. This gap is defined as the difference between the current state of the issue and the aim that the actor has for the issue. The causal relations were added to represent the simplified understanding of the actors of the world. Finally, the assumption was made that this belief structure can be used throughout the different theories. This assumption is required to operationalise the theories on an individual agent level as they lack details on the specifics.

The second part structuring the common core is the iterative stages approach. The common core is composed of three main iterative stages being loosely based on a simplified policy cycle (Bridgman and Davis, 2004; Jann and Wegrich, 2007; Wyner and Benn, 2011). The first round is the world simulation that helps provide the states on the issues in the belief hierarchies of the actors. The second round is the agenda setting where the agents choose which issue should be discussed in greater details based on their beliefs. Finally, the third round is the policy formulation where the actors decide which instrument and whether that instrument should be implemented.

The last main component of the common core comes with the actions that the actors can perform. These actions are limited to actions that can be used by the actors to influence each other's beliefs. They therefore contain actions that can influence the causal relation in the belief hierarchy, the states of the issues and the aims of the issues. The actions are then split in two parts: the choice of the action and the impact of the action. Originally, the actions are chosen by the actors depending on their impact on the preferences of other actors. This approach was formalised and implemented. However, and this is shown in Chapter 3, it can be argued that the decision on which action should be performed should be decided depending on the likelihood of performing an action. This likelihood is obtained by seeing on whether an actor will discuss a specific issue with another actor depending on beliefs, awareness and political affiliation. The action chosen is then implemented. The impact of the action is then dependent on the resources and the actual beliefs of the two actors. Such actions are derived loosely on the policy entrepreneurship model and the ACF and based on the architecture of the belief system. The aim behind these actions is to have the least amount of actions that can be performed by the actors to decomplexify the model as much as possible. Ultimately, the aim behind this actions is to gain policy learning throughout the network of actors.

The common core is supplemented by four extensions, one for each theory. Each of these extension provides theory specific concepts that cannot be incorporated into the common core as it conflicts with other theories. The three streams and ACF extensions are conflicting extensions that cannot be used at the same time. The feedback and the diffusion theory extensions can however be used with all other theories without conflicting.

The three streams theory extensions adds three main components to the conceptualisation. The first one is the policy hierarchy. This hierarchy is modelled as a mirror to the belief hierarchy. It contains policy instruments ordered in tiers which have an impact on issue in their associated tiers in the belief hierarchy. This allows for the second concept: the choice between problem and policy. During each round, actors can choose between either a policy or a problem. This choice is made based on the preference of the actors. Finally, the third concept introduced is the concept of teams. These teams are formed by actors that are looking to further a specific issue.

The feedback theory extension adds feedback effects to the policy instruments that are implemented by the actors. These feedback effects are not known by the actors and can affects three distinctive part of the model. The form of governance feedback effect is not introduced in the model as it did not fit with the approach taken (it is beyond the scope of what is addressed in the model).

The ACF extensions adds one main concept: coalition. These are formed between actors that share similar beliefs and are long-lasting groups. They are created to encourage policy learning with the policy subsystem.

Finally, the diffusion theory adds a set of concepts. The diffusion theory requires the presence of multiple subsystems and a subsystem network. This network defines the relation between the different subsystem according to the diffusion theory (Mettler and SoRelle, 2014). The diffusion theory also introduced additional actions related to the original actions and which are only used between actors in different subsystems. These are also related to the type of relations that the subsystems share. Several parts of the theories could not yet be integrated within the model however. This is the case of the introduction of new issues or new policy instruments between subsystems. This could be introduced in a future conceptualisation if it fits within the scope of the model created here.

Overall, this conceptualisation attempts to use most of the concepts present in the different theories into a simplified model. The number of concepts introduced in the model is important. This is summarised in Appendix G. However, the resulting conceptualisation remains complex. It is however argued that a simpler model would not allow to represent nearly as much of the complexity of a real policy emergence model. A leaner approach would arguably not allow for the display of policy emergence at all.

***How can this conceptualisation be formalised such that it be implemented in a simulation model?***

The formalisation follows from the conceptualisation. The conceptualisation helps to operationalise a lot of the qualitative theories into a coherent and formalisable story. Because of this, most of the concepts outlined in the conceptualisation are directly translated into the formalisation. This is the case for the agents, the belief system or the iterative stages system presented above in the common core. The different concepts presented for the extensions were also formalised from the conceptualisation. There are however a number of concepts that needed to be detailed such that they be formalised.

The first such concept is the concept of resources. The conceptualisation states that the resources stem from the political affiliation of the agents. However, there are no details on when and where these resources are used and how much resources are used for which actions. To implement the concept of resources, the formalisation required greater details. A lot of the decisions regarding the attribution of resources were made arbitrarily or based on common sense. This is how it was decided that a small percentage of every agent's resources is dedicated to the maintenance of their policy network. Furthermore, it was also decided that the remaining resources shall not all be spent at once by the agents on influencing actions but that they should be spent in steps to allow for more actions to be performed each round by each agent.

The formalisation also required the conception of a sequence of steps for the future model. Which actions are performed first and by whom. The outcome was a cycle for each model that is the same but with some added parts depending on the extension being used. The three streams and ACF add actions related to the teams and coalitions respectively. These actions are performed before the agents individual actions. This is done such that the resources remaining after the team and coalition actions can be used by the individual agents to perform their own personal actions.

The conceptualisation also remains vague on the details regarding the teams and coalitions. The formalisation helps bridge the gap between qualitative and implementable actions. In the formalisation, a series of steps and procedures are devised for the creation of teams by the agents. This is done along with how teams are maintained alive or disbanded. Additional procedures were formalised to calculate the belonging level of the agents (how much of their resources are they willing to assign to the team). All of these decisions are assumptions that are taken by the author and do not rely on any literature as no literature provides this level of details. Ultimately, other researchers could find some of these assumptions questionable and modify them or add additional ones. A remark was made on this topic in the results section as it was shown that the teams do not behave as expected. The formalisation introduces the same for the coalitions with a procedure that is used to construct these coalitions. This procedure is one of many that could be devised and could ultimately be changed or adapted by other researchers based on empirical findings or in order to examine the impact of the change on the behaviour of the model. .

The literature states that teams and coalitions can perform actions. This was integrated within the conceptualisation. The formalisation helped provide clarity on what actions can be performed, who can perform these actions and according to which beliefs from the members is the action performed. For simplicity the actions are the same as the one presented before. A difference was then made between the teams and coalitions. In a team, as it is a temporary group, all members assess all possible actions. It is then assumed that the best action (best new preference or highest likelihood depending on the approach) is selected from all these actions. However, because it would be hard to define what is the belief system of the team, each action assessed by the members is done so based on their own beliefs. The network considered is the team's network and so are the resources. For coalition the approach is different as coalition are considered to be more centralised and have a more powerful leader figure. The actions are therefore assessed and implemented by the coalition leader based on his/her beliefs and the coalition's network. The coalition can be seen as a way for the coalition leader (which by definition has the mildest beliefs and the largest network) to be provided with more resources to perform belief influencing actions. In summary, the approach taken can be seen as a team being a collection of agents that share similar beliefs but that go individually to outsider agents to convince them. The coalition is a collection of agents with similar beliefs that acts as one based on its leadership.

Overall the formalisation was used to bridge the wide gap that is present between the conceptualisation and the implementation. This gap is present due to the lack of details present in the literature. A lot of the assumptions made are based on common sense and observation of the real world. They are not validated assumptions. This means that further research could be used to help validate the approach taken here or refine it. For the purpose of this thesis, this approach is sufficient and allowed the author to design a model that can be used to observe policy emergence.

***How does the proposed formalisation advance the study of the policy emergence process as it relates to the four theories analysed?***

The conceptualisation and formalisation both provide considerable insight into the policy emergence process and forces future researchers to think about the operationalisation of these theories on different levels (system, teams, coalitions, actors). Ultimately, this model could be used as a formidable tool for political scientists to study different policy emergence cases around the world.

The first advancement is the formalisation of all four theories into one common model with its extensions. This provides a structure for future researchers on how the policy emergence process simulation can be approach. It also provides a certain structure for the use of other theories that could be considered. This is the case for the punctuated equilibrium theory for example (Cashore and Howlett, 2007). It also provides a basis for the introduction of processes related to the policy emergence. This is the case for the creation of policy instruments as shown in Taeihagh et al. (2009).

Using this model provides the ability for researchers to test different types of scenarios. This can be done through the use of external events. The number of possible external events is only bounded by the events that occurred in the case study and/or in the imagination of researchers. They can therefore study the impact of these external events. They can also build scenarios with different successions of external events. This freedom in the use of external events will allow a more in depth analysis of the system and how it responds to external events than a simple qualitative study. This is the first advantage of this model.

This model also allows the modeller to compare different policies and instruments. The aim here is not to test the impact policy A versus policy B but to gauge the response of the political arena to the introduction of a new policy in the system. Depending on the policy network and the resources distribution in the political arena, the selection of that policy instrument will vary. Although, one cannot expect a prediction, the modeller would certainly be in a position of looking at the behaviours in the model due to the introduction of a new instrument. For example, what happened to the policy network or the agents' beliefs when a new instrument was introduced. This approach would be adequate for a post analysis of a case study to attempt to understand what occurred and what should be changed in the future. It could also be used to advise current decision makers on their decisions and what the impact of these decisions would have on their network and on the political arena in which they evolve.

The number of parameters present in the model allows for the representation of different institutions and different legislative processes. This is an important aspect for researchers that want to compare different countries which have adapted drastically different policy instruments for similar case studies. This could be the case, for example, with the issue of smoking bans (Cairney, 2007; 2009; Duina and Kurzer, 2004). The model can help understand at what point the differences in the specific situation of each country led to the differences in the policy emergence process.

Because of its complexity and its potential total amount of outputs, the model can also provide an in-depth understanding of policy emergence dynamics. Researchers can look at which agents have more impact on other agents over time and understand why that situation occurred. There is also the possibility of studying the policy network dynamics. This can be done at the overall network level but it can also be done at the team and coalition levels. At this level, temporary shadow networks are created for the teams and coalitions to interact with the agents not included within them. The researcher can look through these network to analyse the impact of the teams and coalitions during the policy emergence process.

Finally, the model allows for the tracking of the policy learning for each of the actors. As each agent has a record of his/her perceived belief of the other agents, it is possible to track how the policy learning is evolving and for what issues or causal relations within the belief tree. This could provide particularly interesting insight in the propagation of knowledge within the model if these partial knowledge trees are appropriately initialised.

***Can the model simulated capture the dynamics hypothesised in the policy making theories? What are its limitations?***

It was mentioned within the results section that the model can indeed simulate most of the behaviours hypothesised by the policy making theories implemented. For the three streams theory, these behaviours are not obtained as outputs but instead are modelled directly into the conceptualisation and the formalisation. For the ACF, policy learning was clearly demonstrated along with the coalition dynamics as formulated in the literature (Jenkins-Smith et al., 2014). One dynamic that was not observed however is the difference in belief evolution in the different belief tiers in the belief hierarchy. This can be explained by the approach taken in the conceptualisation and formalisation and the lack of actions at the highest level of the belief system. The amount of resources provided to the agents in the policy formulation and the agenda setting processes were the same leading to the same policy learning speed in both processes.

Despite all its positive aspects, there are limitations to the model developed in this thesis. These limitations are mostly related to the complexity of the model and as a consequence, the required inputs. The first limitation is related to the amount of required inputs for the agents. There are two main ways for a modeller to approach the selection of inputs for the belief trees of the agents and the policy network. The first one would be to model the real world as is within the policy emergence model. This would consider using the same number of agents as in the real political arena, conducting interviews with the actors to populate the belief trees and obtaining an deep understanding of the policy network. This would require a large number of semi-structured interviews as was done before in Markard et al. (2016). This is a process that is expected to take a lot of time. It could even take more time than conducting an actual qualitative study of the case at hand. Furthermore, the size of the model resulting from such an approach could result in a staggering amount of data to be processed and analysed. However this approach provides researchers with a ready-made infrastructure that corresponds with their choice of theory. This should save them the time and effort of conceptualising, formalising and coding a new model. This approach would also allow researchers to get a more in depth understanding of the evolution of each of the agents in the model.

The second approach would be destined to a less novice researcher in modelling or programming. This method would still require an extensive analysis of the actors and their network. However, the researcher could then use this data to produce a model that is representative of reality. This approach would be similar to the one presented in this report. The number of agents is kept fixed but their respective resources are representative of the case study considered. The beliefs of the actors would have to be approximated and mapped to the few agents present in the model. The policy network would be more complicated to represent but could be approximated in the same manner. This approach would require a lot of assumptions on the case studies and could require more testing to make sure that the settings and assumptions are right. Just as modelling is, this is more of an art than a science. In this case, this is a problem. The resulting model would however be smaller and more manageable. The results and analysis could also be of more interest than the full model. However, it would not be possible to look at the behaviour of individual agents to compare with the real world. The results at the policy emergence level would be most interesting.

The second limitation relates to the size of the model and the number of parameters that one uses in the model. Although the number of parameters is an asset, it is also a limitation of the model. Researchers using the model will need to have a full understanding of what each of these parameters does if they want to change any of them. Furthermore, the setting of these parameters might need to be tweaked depending on experiments performed or case studies being looked at. This is a complicated and time consuming step that makes such study cumbersome. This is also particularly important for the initialisation of the partial knowledge. How these partial knowledge belief trees are initialised has a large impact on the subsequent proceedings in the model as it affects all agent actions performed.

The third and last main limitation relates to the data analysis. Considering the amount of data that can be obtained from the model, this step of the simulation will either require a complex graphic user interface or a programmer/researcher that can process the data in graphs. The researcher will also have to pinpoint his interests to be able to limit the output data to a manageable size. This limitation is linked to the computational efficiency of the model as well. The implementation of the model was done in a simple way, This means that the code is not currently parallelised, making the simulation computationally burdensome. The only way to speed up a set of experiment is currently to run each simulation on a different processor. This reduces only partially the computational time needed to run an entire set of experiments. An ACF simulation can still take anywhere between 2 and 24 hours depending on the number of ticks and agents present in the model. Furthermore, this computational inefficiency is also present at the results level. To produce graphs, the researcher has to search through billions of data points in different `.csv` files. This is highly inefficient and although this step can be highly automated, it remains time consuming. Producing graphs on items such as the policy network evolution can take up to a day depending on the size of the output. This could however be sped up using different data structures to save the outputs.

Overall the limitations are related to the model size and complexity. This calls into question the use of this model against the use of a more traditional and qualitative method for case studies. The choice here has to be made by the researcher. The model might be more appropriate for the comparison of case studies dealing with the same industry or field but in different countries. This could help try to understand why similar or different outcomes emerged in different countries over similar issues. This could be done by using varying initialisation inputs for the same or a similar world model. For single case studies, the simple fact of gathering the data for this model would be sufficient for a qualitative study already. In most cases, this will be sufficient for the researcher. In cases where it is not, then the model could also be used. It is also possible for the modeller to use both, starting with a qualitative study and use this data to further his/her research with a quantitative analysis.

## 8.2. Reflections

Before the conclusion of this thesis, it is necessary to reflect on the important part of this work. This is done in sections. The first part concerns reflection on the scope of the work presented. Then a reflection is performed on the model complexity which has come up throughout. Some thoughts are provided on the agent actions as they were formalised. A reflection is then done on the simulation issues and how they can be addressed in the future by other researchers. Finally, the modelling method and the scientific contributions are looked at.

### 8.2.1. The scope

The scope of the work presented was initially very wide. The aim was to first conceptualise and formalise the three streams theory, the advocacy framework coalition, the feedback theory and the diffusion theory into a common structure. The second aim was then to implement the developed formalisation into an agent based model. Finally, to appropriately complete the work, it was important to analyse the initial results from the agent based model.

As the report has shown, the scope was a little too large considering the time constraints provided by the master thesis length. This leads to some the removal of some of the parts from this original plan. The feedback and diffusion theory were therefore not implemented within the Python code. The results analysis was also severely limited. The output from the simulation revealed both the large range of data it yields, and the extent of effort required to analyse them due to their large volume. Thus, the results chapter was limited to demonstrating the agent behaviours this thesis set out to model, and the potential for different types of model analysis, which is a project in and of itself. This was due to the time it took to run one simulation but also to the time allocated for the analysis of the results. Finally, and this was mentioned throughout the report, because this work is an iteration type of work, the conceptualisation and formalisation were updated through to the end of the thesis and they are provided in the Appendix A and Appendix B. However, for the sake of consistency, the conceptualisation and formalisation presented in the body of the text remained the basis for the final code implementation.

### 8.2.2. The model complexity

The complexity of this model was model several times throughout this report. The model developed is a large model that includes a number of actors, a number of actions for each of the actors, teams, coalitions and a specific cycle that is followed by the actors. The main reason behind the size of this model is the belief system. This belief system is used as the centre of the approach taken. All of the actions that the actors can perform are actions that are related to this belief tree, may it be related to choosing an issue or to influence other actor's issues. This calls into question whether the belief system is at all required within this model and what could replace it if it is not.

This issue with the replacement of the belief system by another approach is that this other approach would need to relate to the beliefs of the policy network actors in some way.

The author could not find in the literature occasions where different approaches could be used to obtain the same outcome.

It might however be possible to simplify the structure of the belief system considered. The belief system is composed of four main parts: the tiers, the causal relations, the aims of the agents for each issue and the perception of the states by the agents for each issue. The tiered approach is related to the number of steps used within the process considered. If one were to consider adding another agenda setting step, then an additional tier would need to be added. This is not directly related to the complexity of the model as it is related to the design of the model. Furthermore removing or adding tiers does not have an impact on the number of actions the actors can perform.

This means that there are only three actions remaining all related to the issues. The aim and perception concepts are widely used with in the literature (Henry and Dietz, 2012; Holsti, 1962; Matti, 2009). It would be difficult to not consider them. The causal relations are however not required. They were introduced to define the concept of actor understanding of the world. Although this is important, it is not crucial and could be removed. Such removal would decrease the number of possible actions from three to two slightly simplifying the model. It would however remove a key part of the model: framing. This is a common action that political operators perform in the real world and which can have important consequences. The author would therefore argue that simplicity beyond the current model would lead to a loss of accuracy in the representation of the belief of the agents which is not deemed necessary.

Although the model complex, the emergence process is limited. The main emergence process that can be observed within the model is the emergence of policy instruments from the agents' choices. However, the policy instruments are not decided by the agents, they are a limited set provided by the modeller. If there is no satisfying policy instruments, the agents will still have to choose one of the instruments. One way to remedy to such a problem would be to add extensions to the model that would attempt to provide a greater emergence for the policy instruments. This is proposed in the further work section with the introduction of an extension based on the work of Taeihagh et al. (2009).

Two issues arise when considering the addition of more extensions to the model. The first one relates to the model complexity: doesn't the addition of more and more extensions lead to a more complex and unwieldy model? Considering the size of the current model, adding more extensions would only make the model bigger and more complex. The problem here relates to the overall goal of this work which is to share this model and make it available to the research community for use or modifications. However, for every addition from the community, the model will become larger and it will become harder to assess its validity. Furthermore, it will become more and more unlikely that any one researcher has a profound understanding of the entire model. It will gradually become harder to use. So, although extensions could add to the usefulness of the model, ultimately they could also have an inverse impact.

The second one goes as follows: how many extensions are needed to claim that real emergence is occurring in the model? By adding extensions, especially with regards to the instrument emergence part of the model, one can only push the boundaries of the model. It is virtually impossible to endogenies enough concepts to get to the point where emergence becomes universal. For example, if an extension integrated a set of ingredients that can be used to construct policies and if a way is found for the agents to create these policies using the ingredients they are given, there will still not be no emergence of the ingredients. This is particularly important for unknown unknowns which cannot, by essence, be captured in a model.

### 8.2.3. The formalised actor actions

There are three important points that need to be reflected on when considering the actions of the actors as they were formalised in this report. First, it should be said that most of the literature does not consider actions in its literal sense. In most cases, the literature will argue that actors can frame specific topics or influence one another. Little details are provided beyond such descriptions. The three points addressed here relate to the lack of the ability of actors to lie within this formalisation, the actions that were formalised and the formalisation of the three streams theory problem versus policy issue.

Within the model, the actors cannot lie. The conceptualisation provides a way for actors to be influenced by their biased policy network but not to lie. As shown previously, the external parties will select states that they are only interested on and pass on the information they have gathered only on these states. Furthermore, this transmission of the states for each of the issue will depend on the affiliation of the external parties meaning that the states will be perceived differently by different actors. However, the external parties do not have the ability to distort the reality or to outright lie.

Considering current political developments, this can be seen as an oversight. Current events have shown that in some cases, the external parties will outright lie or will deform the reality before informing the rest of the population. This can have a large effect on the outcome of the policy network and the beliefs of the constituencies. However, a different mechanism that relates to the influence of the constituencies (or electorates) is present in the conceptualisation. This is the mechanism that sees constituencies being influenced by the external parties on their goals. If the goals of the external parties are managed in such a way that they are contrary to the current states (through external events scenarios for example), this will lead to a large change in the aims of the constituencies. In effect this can be seen as lying to the population. It is not at the level of transmission of the states but at the issue aims level.

The actions that are used within the formalisation total a number of four as is mentioned before and when considering the three streams theory: the aim influence, the state influence, the impact framing (only for three streams) and the causal relation framing. The formalisation also adds that external parties are apart and can only perform two actions to influence other actors: causal relation framing and impact framing (only for the three streams). Note that this does not consider the passive actions of transmission of the states as it is not an influencing action and electorate influence as it does not involve two active actors. For this choice, it was assumed that the external parties should only be able to frame. However, after reflection and considering the model complexity this approach which sees the external parties as special actors, is considered inappropriate. It is also hard to argue that the external party can only do two actions and not any of the other actions considering the lack of evidence in the literature and the complexity present in the real world.

To simplify the model and its understanding, it was therefore decided to change the actions of the external parties and to align them to the actions that the other actors can perform. This means that all active actors now have four actions they can perform putting them all on the same level. The only difference is related to the external parties and the way they influence other actors. They usually influence using wide channels like reports, studies or through the media. It can therefore be argue that this account as blanket influencing. The actions of the external parties are therefore all blanket influencing actions. The changes stemming from this reflection are reflected in the appendices which have amended version of the conceptualisation and the formalisation.

Finally, it is interesting to reflect on the three streams theory and more specifically how the actors choose between policy or problem. This issue of an actor having the ability to choose a policy or a problem was an important one. Following the literature, it was considered that the actors should have the possibility to choose a policy or a problem (Zahariadis, 2003). Two approaches can be used for this. Either actors are set up to by default select a policy or a problem in such a way that there is a comparable amount of actors choosing policies and problems. This approach is not so much a choice for each actors as it is a quick fix on how to approach the three streams theory.

The second approach, and this is the one that was selected, was to provide a real choice between policies and problems for each actors. Considering this choice is made based on grades assigned to the problems and the policies, it would mean that the grades between the two would have to be comparable. This is to avoid favouring one of the two each time. The way the grades are calculated is through the impact of the policy on the gap of the issue for the policies and the impact of the change of the gap of an issue on the higher tier issues for a problem. The author still believes that this approach could be enhanced or modified such that the calculation of these equations can be more easily justified. The current approach results more as a coincidence that the equations chosen provided for equivalent grades more than because of literature or other findings.

### 8.2.4. The simulation issues

As mentioned throughout this report and this chapter, there are a number of simulation issues related to the approach used for this model. The first of these issues is related to the inputs. As mentioned before, the inputs both on the policy emergence parameter side but also on the agent and policy network side are considerable. Issues also arise with the connection between the world and the policy emergence model. It is difficult to provide a consistent approach on how to build a robust link between the two models that will always work.

Some advice can be provided considering these issues and with the aim of helping on the introduction of case studies within the model. It is highly improbable that any researcher will have time to collect the necessary information on all agents present in a case study along with categorising them into an appropriate belief hierarchy. This would require dozens if not hundreds of interviews with actors which would have for goal to assess the belief of each of the interviewees for all issues present in the hierarchy.

An alternative procedure would be instead to focus on the construction of the belief hierarchy and the connection between the world and policy emergence models. The procedure to obtain the belief hierarchy is up to the modeller and will depend on his/her expertise. In most cases, there will be a need to either build the belief hierarchy and the connection with the person that built the world model or with decision maker actors from the case study in question or both. Through unstructured interviews the researcher could get a wealth of information what the actors believe are the issues within the model. It will then be up to the researcher to build the belief hierarchy based on the data collected in the interviews.

This same method could be used to build the connection. The main issues to solve there is to find out how to map the issues found in the belief hierarchy to a [-1, 1] interval. To get this mapping, for some issues, the researcher will have to assign what is widely believed to be a maximum or a minimum for the given issue. This kind of information can be obtained through the interviews and can be tested later on by simulating the world model only with the states calculation. This same steps can be used for the calibration of the world model.

### 8.2.5. The modelling method

The method used to implement the policy emergence model formalised was chosen as being an agent based method. It was chosen because of the need for an agent based method following the formalisation of the model. The formalisation explicitly mentioned the need for agents to perform actions. After having implemented and simulated the agent based model created, it can be said that the agent based approach used was the appropriate modelling method. There are no other methods, to the author's knowledge, that would be able to simulate the policy emergence process in such depth without using agents. Statistical analysis or similar methods would not be sufficient.

As mentioned before in this report, this is different for the world model implemented. The world model could be a discrete event simulation, a system dynamics model, an econometrics model or any other type of model. The only problem would then be to connect it to the policy emergence model. Regardless of how the connection is made, this model does not need to be an agent based model. The agent based forest fire model was implemented here for simplicity and due to time constraints.

### 8.2.6. The overall scientific contribution

The main scientific contributions of this work are twofold. The first contribution regards the policy making theories. As mentioned throughout the report, the different theories used in this work are highly qualitative theories. And for the most part, they are high level theories which are not detailed in any ways. This was shown to be particularly problematic for the three streams which has a very global approach without any concerns for the details of actor interactions for example (this is why it was supplemented with the policy entrepreneurship model). The contribution of this work is the formalisation and detail requiring implementation of these theories. Assumptions and choices had to be made. Whether these choices are correct or flawed, they have led to the raising of the issue of formalising these theories and should awake other researchers working on policy making theories on the importance of detailing their work. It could also have an effect on theories themselves and lead to some adjustments through the use of case studies and their simulations.

The second contribution relates to the policy emergence process simulation. Throughout the literature, very few simulations were implemented for the policy making theories considered in this work (Zahariadis, 2003). The implementation and simulation of the theories therefore provides a new approach for the policy emergence community. It should also allow other researchers to follow in similar endeavours advancing the field forward. This work has shown that the simulation of these theories is possible. It is then up to other researchers to decide whether these simulations are useful or whether adjustments and modifications are required to make them useful.

## 8.3. Further Work

The work presented in this report was just a preliminary test of the integration of the different policy making theories together into one model. This work is far from being finished. The detailed further work list through of by the author is outlined in Appendix F. The first two main aspects are the implementation of the diffusion theory and the feedback theory. These two theories are not yet present in the Python code which only currently includes the three streams theory and the advocacy coalition framework. Furthermore, the policy broker concept from the ACF was only considered in the conceptualisation but it was neither formalised nor implemented.

Due to the overall amount of parameters but also to the computational efficiency of the code, not all possible parameter studies were performed within this work. This analysis would be required for further work to better understand the impact of each of the parameters present in the model and whether they were appropriately conceptualised.

An important part of the formalisation which has yet to be introduced in the Python code relates to the states selection by the external parties. It was theorised that the external parties will not necessarily be interested in all states but will focus on specific states related to their core interests. For example, a NGO concerned by the environment will be less likely to be interested in states related to education. This approach of selective information still needs to be implemented. It is expected to have a major effect on differentiating the states that each of the agents perceives in the model. This should lead to drastically different results compared to the results presented within this report. The resulting model would be more dynamic. It would also address the subject of media influence more appropriately according to the literature (Birkland, 2004; Cook et al., 1983; Kosicki, 1993; McCombs and Shaw, 1972; Van Belle, 1993; 2000; Waldherr, 2014).

Throughout this report, the partial knowledge belief initialisation has been mentioned as an issue. This initialisation is what defines the warmup time. It can have a large impact on the results of the model. It would therefore be important to conduct a thorough study of how these partial knowledge trees should be initiated. It would be important to know if a fully random set of values is more effective than a distributed set of inputs depending on affiliation of the actors and the issues considered.

Currently the policies and policy instruments are being specified as inputs by the modeller. There are however ways to extend this approach into an endogenous approach where it is the agents that create the policies they want to consider. An approach similar to the one presented in Taeihagh et al. (2009) could be used for this. This would be added as a module to the current model and could use the already developed agent based model developed in Taeihagh et al. (2009).

As mentioned in the limitations, the model and the analysis of the results are currently using code that is inefficient at best. Further work could focus on trying to parallelise some of the code being used to allow for greater computational efficiency. This could be done at the action level where the different actions could be performed at the same time. This should not have an impact on the overall outcome as long as the actors are still performing their actions in a random order. Regarding the results analysis, the current approach uses multiple python files with very little difference. It could be worth the time to write a large python file that would be able to easily parse through all outputs and produce the necessary graphs. The issue there is that such an approach would require a very large amount of memory and would produce thousands of graphs per experiment set. A compromise should be found between efficiency and practicality of search results analysis.

The current outputs considered are limited. This was highlighted multiple times within the results chapter. Future researchers should look at ways to save the actions that have been performed, by whom and with what impact. This would allow for a greater understanding of the results and ultimately a better understanding of the model behaviours.

It would also be important to perform a full-fledged case study. In the work presented in this thesis, the case selected is minimal and not grounded in reality. It would be important to use accurate and real inputs and test the model in such an environment with all external events that occurred. This type of study would be able to validate the approach taken to see whether the model can be used to reproduce what a qualitative study would have done. It would also have a much greater value at establishing a procedure on how to systematically approach the creation of the belief system for the agents and the calculation of the states.

## 8.4. Conclusions

***To what extent can a formal simulation model represent the policy emergence process theories?***

The formal simulation presented in this report can represent most of the concepts, dynamics and processes that the four policy making theories describe. This work demonstrated that conceptually and formally different policy making theories can be modelled into one common model with extensions addressing each theories specifically. It was further demonstrated that this can be implemented for the three streams theory and the advocacy coalition framework. Due to time constraints the two other theories could not be implemented.

This work was initiated with a broad literature study on the four policy making theories. The aim of this literature study was to gain a better understanding of the theories and isolate the main concepts from the qualitative theories. Using these concepts, the conceptualisation for the model was devised. This conceptualisation used the common concepts to build the common core. This is the part of the model that is common to all policy making theories considered. It is composed of the concepts that are compatible from the different theories. The incompatible concepts are used to build the extensions for the different models dedicated to the specific theories.

Before being able to implement this conceptualisation, the formalisation is done so as to fill in the gaps needed to implement the model. This consists of providing the equations for the actions of the actors, how the resources are spent by the actors, how teams or coalitions are created, how preferences are calculated. The end of the formalisation marks the point where the model can be coded. This was done in Python using a modified and enhanced version of the Mesa Project. Following this implementation, a series of experiments are designed to explore the model. The first experiment performs a variable sweep to see what the impact of changes in the most important variable is. The two other experiments devised introduce external events to see whether they have the expected effects on the models.

The results from these experiments are two-fold. The results regarding the emergence of the agenda and the policy instrument are flawed by issues with the connection between the world and the policy emergence model. The rest of the results however shows the policy learning occurring within the agents' belief systems. It also displays team and coalition behaviours which are mostly coherent with the formalisation of these concepts and with the original theoretical conceptualisation.

Following this work several aspect remain to be addressed. The implementation of the feedback theory and diffusion theory along with the new less complex formalisation which was discussed in this chapter and which is present in the appendices. Beyond these required additions, additions that would ease the use of the model or increase its computationally efficiency could be important. Finally, and this is the primary aim of this model, other researchers could change or modify current components of the model depending on their approach of the policy making theories. They could also build new extensions to enhance the present model.

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# Appendices

# A

# The Revised Conceptualisation

This chapter presents the entire revised conceptualisation. It was revised after reflection on the actions. The formalisation is similarly revised in the next appendix.

## A.1. Common core

The policy emergence process is a process composed of several **iterative stages**. Different iterative stages can be differentiated. There are iterative stages where the **actors** present in the **policy arena** interact with each other. The policy arena is the environment in which these connected actors evolve. Additionally, different types of actors are present within the policy arena. They are the **policy makers**, the **policy entrepreneurs** and the **external parties**. The policy makers are the actors that have decision making power. This means that they can decide what is placed on the **agenda** or what **policy instrument** should be implemented. The former is performed in the round called the **agenda setting** while the latter is perform during the round called the **policy formulation**. They can also work to influence the **beliefs** of the other actors present in the policy arena which are connected to them through their **policy network**. The policy network is the network that connects the actors present in one policy arena. The actors are connected based on their awareness of one another. The likelihood of actors to interact with one another is dependent on their awareness of one another. Over time the policy network of the actors will deteriorate. To maintain their network, the actors are able to perform simple actions using their **resources**. These resources represent their financial and political resources.

Each policy maker possesses a belief hierarchy that defines its beliefs on the issues being discussed in the policy arena. This hierarchy is composed of field wide beliefs at the top and beliefs on increasingly detailed issues when progressing downwards in the hierarchy. Example of issues are public transportation or the amount of plastic present with a size less than 2 millimetres present in the oceans. For each of these issues, the actors have an understanding of the current **states of the world** and a goal for where they would like to see this issue be. Furthermore, each level in the hierarchy is connected to the next through causal relations up to the highest level. These causal relations help the actor understand how different issues affect each other and therefore how the world works.

The impact of the influence of the policy makers on the other actors is dependent on the resources spent by the policy makers, the difference in beliefs they have with the actor they are influencing and the affiliation of both influencing and influenced actor. However, before influencing other actors, a decision must be made on what influence should be performed and on which actor. The likelihood that a policy maker will influence another actor will vary depending on their **political affiliation** in relation to the affiliation of the actor influenced, their perceived **conflict level** on the issues concerned with the actor influenced, their policy network (awareness level) and whether the actor being influenced is a policy maker or another actor. Within the policy arena, actors will prefer influencing policy makers as they have decision making power (they decide on the agenda and the policy instrument to be implemented). The political affiliation of the actors relates them to specific **constituencies**. Furthermore, it affects the likelihood of actors of different affiliation of interacting with one another. The resources available to the policy makers are dependent on the size of their affiliated constituencies. There is a conflict level for each issue represented in the beliefs of a policy maker. This conflict level is the difference in the views of the world of the policy maker and what the policy maker thinks the beliefs of the actors influenced are. This perception of actor B's beliefs by actor A is referred to as the **partial knowledge** of the actor A. The amount of conflict level will affect the likelihood of the two actors interacting with one another about certain issues. Actors are more likely to discuss issues for which they have a mild conflict level and less likely to discuss issues for which they have a high conflict level.

There are different types of actions which the policy makers can perform on the other actors. They can perform **framing actions**. These actions are attempts to influence other actors on their beliefs of how the world works (the causal relations in their beliefs hierarchies). The policy makers can also **directly influence** the actors on their beliefs for the issues. They can influence them on the way they see the world or on their aims of what the world should be. Because the **attention span** of the actors in the policy arena is limited, these actors tend to only influence other actors on one selected issue. This issue is selected based on the appearance of **urgency**. This urgency is determined by the actors based on the gap between the current states of the world and their aim but also in relation to the impact that this issue ultimately has on their normative beliefs. The ultimate goals of the policy makers being to reach their normative belief goals.

The partial knowledge of the actors is updated whenever an influencing action is performed. Both the actor influencing and the actor being influenced have been part of the interaction and therefore get a better, but not perfect, understanding of each other's beliefs on the topic of the interaction.

As mentioned earlier, the policy makers can also decide what is on the agenda. This is done by selecting the issue that they consider to be the most urgent to them. The issue that is ultimately placed on the agenda is the issue that most policy makers believe is urgent. The choice of issue on the agenda will go on to define which issues can be discussed in iterative stages looking at lower level issues in the belief hierarchies. The issues all have to be related to the issue on the agenda. This is however subjective to the actors depending on their personal beliefs. The process of agenda setting therefore helps narrow down the problems observed by the policy makers and to ultimately decide on a **policy instrument** that can be used to address such problem.

The policy entrepreneurs are actors that seek to influence the beliefs of the policy makers primarily but also to influence the beliefs of the other actors within the policy arena through their policy network. Their aim is to push their beliefs onto the other actors present in the arena. Similarly to the policy makers, the policy entrepreneurs have a belief hierarchy, a political affiliation and use resources to influence other actors. These resources are also defined based on their constituencies. They can also perform different actions on the policy makers, external parties and other policy entrepreneurs. They can frame how the world works, influence on the beliefs of other actor's view of the world and their goals. The likelihood of performing an action and its actual impact are determined in a similar way as for the policy makers.

The external parties are actors that have multiple roles within the policy arena. The external parties represent actors such as the media, but also research institute or academic institutions. They help inform other external parties, the policy makers, the policy entrepreneurs about the current state of the world. They can also influence other external parties, policy makers and policy entrepreneurs on their beliefs of how the world works, on issue states and on issue aims. Finally, they can influence the goals of the constituencies. Similarly to the policy makers, the external parties have a certain political affiliation and resources stemming from that affiliation.

The external parties have direct access to the states of the world. They can therefore transmit this information to the actors within the policy arena along with the constituencies. However, not all external parties are interested in all states of the world, some external parties are only interested in specific states. Furthermore, this transmission of the states is dependent on the policy network, and the affiliation of the external parties and the actors to whom they are transmitting this information. Different actors will perceive the external parties as more or less trust worthy depending on their affiliation.

The external parties can also influence other external parties, the policy makers and the policy entrepreneurs. They can do this through framing actions, influence on aim actions and influence on state actions that affect all actors present in the policy arena called blanket actions. The likelihood of performing a blanket action is defined the same way as for the policy makers. The impact is obtained as shown earlier on. The impact is however spread on all actors concerned.

Finally, the external parties can influence the goals of the different constituencies through blanket influence. This is similar to the blanket framing that is used on the actors within the policy arena but this time they affect the others' goals. The likelihood of an action being performed will depend on the difference in beliefs between the constituencies and the external party concerned and the affiliation of the external party performing this action. The impact will depend on the resources spent and the difference in beliefs.

Each constituency represent a sector of the electorate and is associated to a political affiliation. Each constituency represents a certain percentage of the total voter population. This representativeness of a constituency is what affects the amount of resources that is distributed to the different actors within the policy arena as mentioned previously. The constituencies can influence the policy makers present in the policy arena. The policy maker's goal beliefs tend to move towards the goals of their constituencies to increase their chance of remaining in office.

A second round can also be identified as a policy formulation round. In this round, the aim is to adopt a policy instrument based on the chosen agenda such that it is implemented in the world. Policy instruments are the specific mechanisms policy makers put in place in order to impact the issues discussed within the iterative stages. During the policy formulation round, the actors influence each other's beliefs similarly to the agenda setting round. The aim here is however different. Each actor selects a policy instrument based on its expected impact in the world. This impact is assessed by the actors based on their beliefs of the change the instrument will have on the states of each issues compared to their own goals. Because the actors have a limited attention span, they can only select what they perceive as being the most appropriate policy instrument. They decide that based on the impact that the instrument have on their beliefs and based on which issues need to be addressed the most urgently. The interactions of the different actors are the same as for the agenda setting round. The likelihood of an action happening is however now determined based on the expected impact that each instrument has on the urgent issues in the actors' beliefs within the narrower field of issues selected in the agenda setting stage.

One main difference is that the policy formulation round does not end with the selection of an issue but the selection of a policy instrument. Furthermore, the policy instrument selected is only implemented if the number of policy makers that support that instrument is superior to the threshold required for the implementation of the instrument. This threshold can be a majority, a two third majority or unanimity.

The last round considered is a round that does not involve the actors. It is the world. In this round, the instrument that has been selected is implemented. The world is affected by that instrument and the states of the world change accordingly. This then has an impact on the belief of the actors present in the policy arena as the change in the states is conveyed by the external parties to the different actors.

Finally external events can be introduced in the model. Such external events can affect anything from the goal of specific agents for a specific issue to a new distribution of the constituencies. These external events are devised based on case studies. The modeller must then adopt the impact of an election into the model's framework to appropriately represent that election.

## A.2. Three streams theory

The introduction of the three streams theory changes some of the aspects presented in the common core. These changes are performed to account for the concept of streams and of policy window. The iterative stages considered are the same as the iterative stages mentioned in the common core. The difference is present in what the actors present in the policy arena choose as an issue. The actors can now choose from a policy or a problem as called for in the three streams theory. The problems are obtained in the belief hierarchy of the actors while the policy are obtained in a **policy hierarchy**.

The policy hierarchy is a hierarchy containing policy instruments. These policy instruments have specific impacts on the issues present in the belief hierarchy of the actors. The concept of policy instrument is therefore the same as the one presented in the common core. Within the three streams theory, policy instruments are present in all iterative stages. Each of these impact is now subjective which means that they also represent beliefs on the effectiveness of the different policies. These beliefs can also be influenced by the different actors present in the policy arena.

Each actor first selects a policy or a problem. The problems are graded similarly to what was previously presented in the common core: based on the perceived urgency of the chosen issue. The policy are graded based on their impact on their associated issues. Whichever grade is the highest will be chosen by the actor. If the actor chooses a problem first, then s/he will have to choose an associated policy based on the effectiveness of the policies. Furthermore, all actions performed by that actor from now on will be on the beliefs of other actors concerning the selected problem. These actions re the same as the ones in the common core. If an actor chooses a policy first, s/he will have to choose an associated problem based on urgency. Similarly to the problem, all actions performed by that actor from now on will be on the beliefs of other actors concerning the selected policy.

The policy actions are similar to the problem actions presented in the common core for the different actors but with one change to the framing action. The aim of the actor is now to affect the impact beliefs of other actors in their policy network. The actions on policies are therefore akin to the framing actions related to the problems. This can only be done by actors having first selected a policy as mentioned earlier. There are some important caveats to this approach. First, the constituencies do not possess any beliefs on the policy hierarchy. This means that external parties cannot influence the constituencies if they have selected a policy first, they will then move on to their problem (which they selected based on the policy first chosen) and influence the constituencies on that problem. Second, the constituencies cannot influence the instrument hierarchy of the policy makers, the influence remains focused only on the belief hierarchy.

Additionally to the introduction of streams, the policy entrepreneurship model which is tied to the three streams theory introduces the concept of **teams**. Teams are small, short-term groups of actors which try to influence other actors on a specific problem or policy. These teams are constituted by actors when they consider that a policy or a problem is very urgent and when they can find other actors that share their beliefs on that policy or problem and the urgency of it. Once a problem or policy has been sufficiently pushed (enough actors have been influenced), then the team will disband and the actor will return to acting separately. Teams use the same actions as the individual actors. They provide actors with a larger policy network. This is because the team network consists of the sum of the networks of all actors present in the team. The teams obtain their resources from their members based on their feeling of belonging within a team. The actions performed by the team have to be agreed by the entire team as team are non-centralised entities. This means that no actor is powerful enough to impose his/her will on the other actors. Teams can also perform influencing actions on their own members. This helps increase the cohesiveness of the team so that they can last longer within the policy arena. The actions performed by team members on team members are blanket framing, influence on goals an influence on states.

Although there are also a set of iterative stages in the three streams theory, the actions performed in both iterative stages are not different anymore. Because each actor must have chosen either a policy or a problem, the actions are exactly the same in both iterative stages for all actors present in the policy network. The difference remains in the fact that for the agenda setting iterative stages, an agenda is set at the end which defines what is discussed thereafter. The agenda is composed of a problem and a policy. Each is chosen as being the most selected by the policy makers. The problems and policies discussed thereafter must relate to the problem and policy on the agenda. They must therefore be on a lower level in their respective hierarchies. For the policy formulation, the policy instrument chosen by the policy maker is the one that meets the threshold requirement once again. This disregard the fact that a policy maker might have chosen a problem first.

## A.3. The advocacy framework coalition

The introduction of the advocacy coalition framework adds some different changes to the common core. The main addition is the concept of **coalitions**. The coalitions are groups to which actors are assigned based on their normative beliefs. They are long term entities that perform actions on other actors or other coalitions to influence them into similar beliefs. Actors only change coalitions when their normative beliefs vary which happens only rarely. The actions performed by coalitions are similar to the ones performed by teams. However, coalitions are centralised entities. This means that the **coalition** leader is the only actor that decides which actions are implemented. The coalition leader is the actor within a coalition that has the largest policy network. Finally, the number of coalitions present within a policy arena is usually limited to only a few according to the literature.

The ACF also introduces the policy broker. Policy brokers are actors that look in their network to put in contact actors which are badly connected within the policy arena. Policy makers, policy entrepreneurs and external parties can all be elevated to the role of policy broker which grants them additional actions. Two actions are added. With the first action, the policy broker can connect two actors which are not connected (but to which s/he is connected). In the second action, the policy broker can raise the awareness level between two actors (if his/her own awareness level is high enough). To perform these actions, the policy brokers is provided with additional resources fitting with the strength of his/her policy network.

Finally, which action is chosen by the policy broker is decided based on the type of policy broker. Neutral policy brokers will select the actions that will lead to the largest impact. This means that connecting actors that are not yet connected will come first, followed by raising the awareness between actors that are already aware of each other. If the policy broker plays an advocacy role, then s/he will select actions with actors that share his beliefs.

## A.4. Feedback theory

For the feedback theory, the policy instruments implemented by the actors are supplemented with feedback effects. The feedback effects have an additional specified effect on different parts of the world or of the policy arena. When choosing for a policy instruments, the actors are not aware of the feedback effects. There are three feedback effects considered.

Some feedback effects have an impact on the constitution of the constituencies. The percentage distribution of each constituency will be affected. Some feedback effects have an impact on the belief hierarchy of the actors opening new issues to consideration in the hierarchy or removing others. Finally, a third feedback effect relates to the link between constituencies and the resources of the actors within the model. This links is affected by this type of feedback effects.

## A.5. Diffusion theory

The introduction of the diffusion theory requires the consideration of multiple policy subsystems. These subsystems can represent different nations or cities for example but they are all regarding the same issues. The diffusion theory specifies the impact that the actors in a subsystem might have on actors of another subsystem. The subsystems share specific relationships ranging from **friendly** to **competitive** while considering **coercive** and

**dominant**. These relationships help define the actions that can be considered between the actors of the different subsystems. Each subsystem also possesses a certain **status**. This status helps define the amount of resources that is provided to each of their actors.

The actors in the different subsystems are all part of a **super-policy network**. This network connects actors between the different subsystems. Through this network actors can influence each other depending on the relationships between the arenas. An actor will consider all possible actions. The actions that is most likely to be performed is implemented.

The subsystems themselves are part of a network. Each subsystem has a link with another. Each of these links are one directional and can be of one type from friendly to competitive. Links that are coercive or dominant also gain a **strength** attribute. This strength attribute defines the influence that a subsystem will have on another when actors from one arena influence actors in the other. The actions that actors can perform is defined by the link that links their respective subsystems.

In the case of friendly relationship, the actor will be able to perform all actions that are available within the common core. These are actions of framing, influence on states and goals for the beliefs of the other actor. The likelihood of performing these actions along with their impact is assessed the same way as presented previously. When considering the diffusion theory with the common core or the ACF, then the actions are only performed on the issues. When it is considered with the three streams theory, then problems and policies actions are possible.

In the case of a coercive or dominant relationship, the actors will force their own goal beliefs onto selected actors in the other subsystem. The likelihood of this forced influence to be selected will depend on the conflict level between the actors and the type of actors that is being influenced (policy makers are more likely to be influence). Considering actions with an equal impact, actions on a dominant relationship will be most likely to happen, followed by coercive actions and finally friendly actions. The actual impact will only include the amount of resources spent, the difference in beliefs between the two actors and the strength of the considered subsystems. Once again, for similar actions, the impact will be largest in a dominant relationship.

In the case of a competitive relationship, the actors within one subsystem will seek to get a better world that the ones in other subsystems. To achieve this, they will change their goals to match the ones of other subsystems. This is also done through interactions. The likelihood of performing such an action along with their impact will is calculated similarly to the actions between friendly subsystems. The main difference with respect to the impact is that the impact of the actions are on the actor performing the action (the actor influences him/herself based on the beliefs of an actor in another subsystem).

# B

# The Revised Formalisation

Due to the iterative process and after a reflection period, several parts of the formalisation was modified. This was done after the code had been implemented, it is therefore not mentioned in the main body of this report. The changes considered are presented here.

Most of the changes considered are related to the way the actions are assessed by the actors and how their likelihood and impact are calculated. In the formalisation presented earlier on, the actions are graded based on their impact on the preferences of the agents being influenced. This is considered to be a stretch when considering real life actions. Instead, it was decided thereafter to use the likelihood of performing an action. This is determined by the agent based on conflict level, awareness of other agents or type of agents. The modified actions and equations are presented below.

Furthermore, as it was mentioned several times within the report, the actions of the external parties are harmonised with the other active actors. They can therefore perform four types of actions but all under a blanket form. The equations for these actions are also provided below.

**Individual framing** The agents can attempt to influence the causal relation belief of other agents. This is an individual framing action. For this action, all causal relations related to the issue selected by the agent are considered. The likelihood to perform such an action depends on several parameters which are outlined below:

$$G_{CW,n_m} = conflictLevel_{CW,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \tag{B.1}$$

where $G$ stands for the grade, $n$ is the influencing agent, $m$ is the influenced agent. $n_m$ is the perfection of the beliefs of the influenced agent by the influencing agent and $CW$ is the causal weight of the causal relation

If this action is selected, as it has the highest grade, then the impact of the action on the beliefs of the influenced agents is given by:

$$CW_m := CW_m + (CW_n - CW_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \tag{B.2}$$

**Individual action - Aim change** The agents can also attempt to influence the aim beliefs on the different issues of the hierarchy of other agents. The likelihood that such action be performed is obtained in a similar way as shown below:

$$G_{A,n_m} = conflictLevel_{A,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \tag{B.3}$$

The impact of such action is then calculated with:

$$A_m := A_m + (A_n - A_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \tag{B.4}$$

**Individual action - State change** Similarly to the influence on the aims of an agent, the states can also be influenced. The likelihood of such an action being performed is given as follows:

$$G_{S,n_m} = conflictLevel_{S,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \tag{B.5}$$

And the impact is calculated as follows:

$$S_m := S_m + (S_n - S_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \tag{B.6}$$

**Blanket framing of the external parties** The actions of the external parties are all blanket actions. The likelihood of performing a blanket framing action is calculated as follows:

$$\begin{aligned} G_{CW,n_m} &= conflictLevel_{CW,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \\ G_{CW,n} &= \sum_{m=1}^{nagents-1} G_{CW,n_m} \end{aligned} \tag{B.7}$$

where $CW$ is the causal weight selected, $n$ the external party performing the framing, $m$ the affected agents considered and $nagents$ the total number of agents.

And the impact is calculated as follows:

$$CW_m := CW_m + (CW_n - CW_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \tag{B.8}$$

**Blanket aim change of the external parties** Similarly to the blanket framing, the aims can also be influenced. The likelihood of such an action being performed is given as follows:

$$\begin{aligned} G_{A,n_m} &= conflictLevel_{A,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \\ G_{A,n} &= \sum_{m=1}^{nagents-1} G_{A,n_m} \end{aligned} \tag{B.9}$$

And the impact is calculated as follows:

$$A_m := A_m + (A_n - A_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \tag{B.10}$$

**Blanket state change of the external parties** Similarly to the blanket aim change, the states can also be influenced. The likelihood of such an action being performed is given as follows:

$$\begin{aligned} G_{S,n_m} &= conflictLevel_{S,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \\ G_{S,n} &= \sum_{m=1}^{nagents-1} G_{S,n_m} \end{aligned} \tag{B.11}$$

And the impact is calculated as follows:

$$S_m := S_m + (S_n - S_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \tag{B.12}$$

**The actions (active agents) - three streams theory** For the agents that have selected a policy, an additional action is added. This action is an action that influences the impact beliefs of the policy instrument selected by the agent. For all agent, this action replaces the framing or blanket framing action. The aim and state influence actions remain the same. The likelihood of performing each action is calculated. Whichever action is most likely to be performed is implemented with a certain calculated impact.

The likelihood of performing a policy action is given as follows:

$$G_{I_{issue},n_m} = conflictLevel_{I_{issue},n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \tag{B.13}$$

where $n$ is the agent performing the action, $m$ is the agent on which the action is performed, $I$ stands for the impact that the action has on the mentioned issue. Note that if the instrument has an impact on four separate issues, then the agent will assess the likelihood of influencing each of the four impacts contained in that policy instrument.

The impact of the action is then given as follows:

$$I_{m,issue} := I_{m,issue} + \left(I_{n,issue} - I_{m,issue}\right) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \tag{B.14}$$

where $n$ is the agent performing the action, $m$ is the agent on which the action is performed.

**Intra-team belief actions - Three streams theory** The blanket framing action on causal relation is used in the case where the team has selected a problem as the issue it is advocating for. The likelihood and impact of such actions are the same as the ones presented in Equation B.15 and Equation B.12 respectively.

The blanket framing action on the policy impact is used in the case where the team has selected a policy as their issue. The likelihood of performing such action is calculated as follows:

$$G_{I,n_m} = conflictLevel_{I,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m}$$
$$G_{I,n} = \sum_{m=1}^{nagents-1} G_{I,n_m} \tag{B.15}$$

where $I$ is the impact selected, $n$ the agent considering the action, $m$ the affected agents considered and $nagents$ the total number of agents in the team.

The blanket framing action on the problem is used in the case where the team has selected a problem as their issue. The likelihood of performing this action on the states is given by the following equation:

$$G_{S,n_m} = conflictLevel_{I,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m}$$
$$G_{S,n} = \sum_{m=1}^{nagents-1} G_{S,n_m} \tag{B.16}$$

The likelihood for the influence of the aims of the problem is calculated the same way but through substitution of the conflict level from the states to the conflict level of the aims.

For each of these actions, the grade is the sum for all agents of the action. The total grades for each action is compared and the action with the highest impact is selected to be implemented.

The impact of all these actions is then given, in order, as:

$$\begin{aligned}
CW_m &:= CW_m + (CW_n - CW_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \\
I_m &:= I_m + (I_n - I_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \\
S_m &:= S_m + (S_n - S_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \\
A_m &:= A_m + (A_n - A_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents}
\end{aligned} \tag{B.17}$$

**Inter-team belief actions - Three streams theory** The framing on causal relation likelihood grade is obtained using Equation B.1, the state influence likelihood using Equation B.5, the aim influence likelihood using Equation B.3 and the impact influence likelihood using Equation B.13

All of the actions are graded and the action with the highest likelihood to occur is the action that will be performed. The impact of each of these actions is then given by Equation B.2, Equation 4.12, Equation B.4 and Equation B.14.

# C

# Technical Model Formalisation

This chapter presents the approach that was used to code the forest fire world model. The model is based on the forest fire model presented in the Mesa project. It was modified slightly to add cells, add types of cells, add firefighters or prevention measures. This changes are limited as they only introduce probabilities of a fire happening or being suppressed. Furthermore, a timer was introduced to help the forest re-grow after a certain amount of time. This is used to be able to run the model infinitely.

## C.1. Calculation of the states

The belief states are calculated for the truth agent. They are obtained using the following equations:

1. DC1 - Economy: A value of 1 would mean that the map is filled with empty and camp site cells and there was no fire. A value of $-1$ would mean that the whole map is filled with burnt cells.
$$Economy = \frac{Tourism + Safety}{2} \tag{C.1}$$
2. DC2 - Environment: A value of 1 would mean that the mao is covered in forest. A value of $-1$ would mean that the map is fully burnt.
$$Environment = \frac{Forest\ size + Safety}{2} \tag{C.2}$$
3. PC1 - Forest size: A value of 1 would mean the map is full of thick forest. A value of $-1$ would mean it is empty of all forests.
$$Forest\ size = \frac{0.75 Thick + 0.25 Thin}{Total} \tag{C.3}$$
4. PC2 - Tourism: A value of 1 would mean that the map is full of camps. A value of $-1$ would mean it is full of thick forest.
$$Tourism = \frac{0.75 Camp + 0.25 Thick}{Total} \tag{C.4}$$
5. PC3 - Safety: A value of 1 would mean that there is no burnt land. A value of $-1$ would mean that everything has burnt.
$$Safety = \frac{Monitoring + Firefighters + Prevention - Camp - Thick}{5} \tag{C.5}$$

6. S1 - Camp sites: A value of 1 would mean the map is covered with camps. A value of $-1$ would mean the map has no camps.

$$Camp = \frac{Camp}{Total} \tag{C.6}$$

7. S2 - Planting: A value of 1 would mean that there area lot of thin forests. A value of $-1$ would mean there is a no thin forests.

$$Planting = \frac{Thin}{Total} \tag{C.7}$$

8. S3 - Monitoring: A value of 1 would mean that the burning probability is of 10% for thin forest and 100% for thick forests. A value of $-1$ would mean the probability is of 0% for both.

$$Monitoring = 0.1 - burning\ probability \tag{C.8}$$

9. S4 - Firefighters: A value of $-1$ would mean that there is the maximum 50% of firefighters extinguishing the fire. A value of 1 would mean there is no change of extinguishing the fire.

$$Firefighters = 0.5 - firefighter\ probability \tag{C.9}$$

10. S5 - Prevention: A value of 1 would mean the map is filled with empty cells. A value of $-1$ would mean the map has no empty cells.

$$Prevention = \frac{Empty}{Total} \tag{C.10}$$

## C.2. The policy instruments

A number of policy instruments are considered within the model. They are presented below. These instruments were obtained arbitrarily. The first ten instruments only affect one secondary issues in the belief hierarchy. For the last six, they affect a mix of secondary beliefs. Each instrument was chosen with its opposite. They are presented in Table C.1

The policies used for the three streams theories at the policy core levels are also shown in Table C.2.

Table C.1: Policy instruments used affecting the secondary beliefs of the agents. Impact 1 is regarding camp sites, impact 2 planting new forets, impact 3 monitoring, impact 4 firefighters and impact 5 fire prevention.

| Instrument | Impact 1 | Impact 2 | Impact 3 | Impact 4 | Impact 5 |
|---|---|---|---|---|---|
| 0 | 0.5 | 0 | 0 | 0 | 0 |
| 1 | -0.5 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0.5 | 0 | 0 | 0 |
| 3 | 0 | -0.5 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0.5 | 0 | 0 |
| 5 | 0 | 0 | -0.5 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0.5 | 0 |
| 7 | 0 | 0 | 0 | -0.5 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0.5 |
| 9 | 0 | 0 | 0 | 0 | -0.5 |
| 10 | 0 | 0.2 | 0.3 | 0 | 0.5 |
| 11 | 0 | -0.2 | -0.3 | 0 | -0.5 |
| 12 | -0.4 | 0.5 | 0.1 | -0.9 | -0.5 |
| 13 | 0.4 | -0.5 | -0.1 | 0.9 | 0.5 |
| 14 | -0.8 | 0 | 0 | 0.9 | 0 |
| 15 | 0.8 | 0 | 0 | -0.9 | 0 |

Table C.2: Policy instruments affecting the policy core beliefs (only used for the three streams model). Impact 1 is regarding forest sizes, impact 2 tourism and impact 3 safety.

| Instrument | Impact 1 | Impact 2 | Impact 3 |
|---|---|---|---|
| 0 | 0.5 | 0 | 0 |
| 1 | -0.5 | 0 | 0 |
| 2 | 0 | 0.5 | 0 |
| 3 | 0 | -0.5 | 0 |
| 4 | 0 | 0 | 0.5 |
| 5 | 0 | 0 | -0.5 |

# D
# The Model Parameters

This chapter presents the different parameters that are present within the model.

## D.1. For the technical model

These are all the parameters that are related to the forest-fire model. These parameters are case study specific and will change when the case study is changed. The initial values used in the model for the experiments is shown in brackets.

1. The initial thin forest burning probability (0.2%): This defines the probability that a thin forest will combust for any tick.
2. The initial firefighter force (10%): This defines the probability that firefighters will intervene in a burning patch leading to a thin forest.
3. The multiplier coefficient between the thin forest burning probability and the thick forest burning probability (10): This relates to the probability that a thick forest will burn compared to the probability that a thin forest will burn.
4. Time for the growth from thin to thick forests (3): This relates to the number of ticks required for a forest to go from thin to thick.
5. Time between burnt patch and thin forest/empty patch (3): This is the number of ticks that it takes for a patch to go from burnt back to empty or thin forest.
6. The percentage between empty patch and thin forest when a patch is past burnt (50%): This is the probability that a burnt patch will go back to being empty versus being a thin forest.

## D.2. For the technical-emergence bridge

The parameters mentioned here are the ones that are related to the calculation of the states and how the technical model is coupled to the emergence model. Changes in these parameters will affect the sensitivity of the emergence model to the initial conditions of the agent's belief trees. It also has an effect on the ultimate control that the agents will have on the overall technical model.

1. Maximum percentage of camp sites allowed (20%): This is used for the calculation of the states of S1.
2. Maximum percentage of thin forests allowed (60%): This is use for the calculation of the states of S2.

3. Maximum thin forest burning probability allowed (10%): This is used for the calculation of the states of S3.
4. Maximum firefighter force allowed (50%): This is used for the calculation of the states of S4
5. Maximum percentage of empty patches allowed (100%): This is used for the calculation of the states of S5.
6. Maximum percentage of thick forests allows (100%): This is used for the calculation of the states of PC3.

## D.3. For the policy emergence model

This section presents all the parameters related to the policy emergence model. In square brackets there is a mention of when these parameters appear in the four different models (backbone, backbone+, three streams (3S) and ACF). In brackets are the values currently being used when they are needed. Explanations are provided when required.

1. Theory choice [all]: The modeller can choose which model to simulate which will select the appropriate cycle. The choice is between backbone, backbone+, 3S or ACF. All these models are mutually exclusive. However the backbone+ builds on the backbone, the three streams and ACF build on the backbone+.
2. The belief tree aims [backbone]: These are all the inputs required for the belief hierarchy of the agents per affiliation type.
3. Number of policy makers [backbone] (6).
4. Number of affiliations [backbone] (3): Note that this code is made to only work for three affiliations. More or less affiliation would require significant changes to the infrastructure of the code throughout all of the code.
5. The affiliation weights [backbone] (0.75, 0.85, 0.95): This defines the influence of agents from different affiliations in the following order: affiliation 1 - affiliation 2, affiliation 1 - affiliation 3, affiliation 2 - affiliation 3.
6. The policy instrument set [backbone]: This relates to the overall instrument set defines by the modeller providing policy instruments and their impact ton the different secondary issues.
7. The distribution of affiliation [backbone] (33,33,34): This defines the amount of resources each affiliation will have. It relates to the electorate representation. It needs to add up to 100%.
8. The electorate influence coefficient [backbone] (0.001).
9. Ratio of policy entrepreneurs per policy makers [backbone+] (3): This defines the number of policy entrepreneurs for every one policy maker agent added to the model.
10. Policy network strategy 1 maintenance and upkeep threshold [backbone+] (30%): This is the thresholds that defines what is the amount of awareness is needed for the links of every agent for the upkeep and maintenance actions.
11. Allowed resources for the policy network maintenance and upkeep actions [backbone+] (4%).
12. The different strategies for the maintenance of the agents networks [backbone+]: This parameter is agent dependent but is currently the same for all agents for simplicity and to have more consistent results.
13. The conflict level coefficients [backbone+] (0.75, 0.85, 0.95): This defines the coefficient used when the conflict is low, mild and high.

14. Partial knowledge sharing randomness coefficient [backbone+] (0.1): This is the coefficient use to set the randomness of the partial knowledge shared. For this value, a number between -0.1 and 0.1 is added to the actual value of the belief when the beliefs are shared after an action has been performed.
15. Action potency coefficient [backbone+] (1): This coefficient is used to make actions more potent. It is a tuning parameters that can be changed by the modeller to adjust the policy learning speed.
16. Resource spent per action coefficient [backbone+] (10%): This defines the amount of resources from the total resources used for actions that can be used for each action. In this case, it would allow every agent to perform 10 actions. This parameter can be used for tuning but also computational efficiency.
17. The awareness decay level coefficient [backbone+] (0.05): This defines by how much the awareness of any link will go down for every tick.
18. Minimum belonging level allowed [3S] (30%): Coefficient defining the threshold below which an agent will have to leave the team.
19. Inter-tick checks [3S] (5): This is the interval between which the agents teams are not checked on whether they still match the team creation criteria.
20. Agent team creation strategy [3S] (strategy 1): This is an agent related input. The strategies are defined in the formalisation. Currently, all agents have the same strategy for simplicity.
21. The number of agents required to start a team for strategy 1 [3S] (3).
22. The gap requirement for the creation of teams [3S] (0.8).
23. The state requirement for the creation of teams [3S] (0.5).
24. Resources used to contact agents for team creation [3S] (2%).
25. Resources used when being contacted for team creation [3S] (1%).
26. Resource spent per action coefficient for teams [3S] (10%): Similar to the backbone but for teams.
27. Principle issue selection for coalition [ACF] (P1): This is decided by the modeller and defines the coalition issue for the agenda setting process in the ACF.
28. The choice of threshold for the constitution of the coalitions [ACF] (0.35): This defines the interval within which a belief is considered similar for the creation of coalitions: [-0.35, 0,35] of the agent creating the coalition.

# E
# Verification

This chapter presents the verification in more details. The different methods that were used to checked the model are outlined. This is done by looking through the code and outlining the issues that arose for the different parts of the code.

## E.1. The belief hierarchy

The belief hierarchy is one of the most complex part of the model. The belief hierarchy structure contains the beliefs of the agent plus the belief of all other agents (the partial knowledge). This is built into a multi-dimensional array.

The belief hierarchy is present throughout the model in most functions. The fact that it is such a complex array means that verification is required throughout to make sure that every time a part of this belief hierarchy is selected, the right indexes are chosen. If the right indexes are not chosen, the code will still run but the results will be completely wrong. This is particularly important for the causal relations which are saved in the array in a certain sequence mentioned within the code comments. Without following this sequence, the code would run but the results would be flawed as it would use the wrong causal relations.

### E.1.1. Preference calculation

For the preference calculation, several checks were performed to make sure the right indexes are selected. The preference calculation is performed for the agent's own beliefs but also for all the partial belief hierarchies in the belief hierarchy parameter. This is needed for the calculation of the best actions later on in the model. For the principle belief calculation, the selection of the right issue was checked, and it was made sure that the preferences of the two issues added up to one. Note that this preference calculation works regardless of the hierarchy structure. Nothing has been hardcoded.

For the policy core belief preference calculations, the selection of the right issue was checked. The selection of only the causal relations with matching sign to the gap in the principle beliefs are also checked. Finally, it was checked that all the preferences on that level add up to one.

For the secondary belief preference calculation, a check was performed that only the issues related to the issue on the agenda are selected. Then the same checks were performed as the checks performed for the policy core beliefs.

For the preference calculation for the policy hierarchies, the same procedures were performed but with the different code considering each of the impacts for each of the instruments. For all these calculations, checks were performed throughout the coding of the rest of the code. Through these checks, it was uncovered that the wrong indexes were chosen in some parts of the preferences calculation. It can now be said with certainty that the right indices are being selected and that the preference calculations are correct.

### E.1.2. Issue/instrument/policy/problem selection

The instrument selection was checked by comparing the actual instrument selected and the preferences of all instruments. The instrument with the highest preference must be the one that is selected by the agent. The same was done for the policies and problems for the three streams model. Check were also performed to make sure that the grade list matches the length of the number of issues being considered.

## E.2. The individual actions selection and grading

Before any actions are performed, the resources are provided to the agents. This was checked through print functions to make sure that the resources were different for agents with varying affiliations as they should be and followed the representation of the affiliation. Furthermore, the resources are then split, for the policy makers and policy entrepreneurs. 20% goes to the policy network actions while 80% go to the individual agent actions. This was checked to make sure that the resources are divided properly.

### E.2.1. Network upgrade and maintenance actions

The network actions are then performed by all active agents. For this, it was made sure that the list of agents is shuffled so that it is always a different agent that is selected first. Two algorithms are used here. One for the agenda setting and one for the policy formulation. For each two strategies are possible as developed in the formalisation.

**Agenda setting** For the first strategy, checks were performed on the while loops. These loops allow actions to be performed as long as enough resources are left. Checks were then performed to see whether the links added to the list of links to be maintained did indeed meet the requirements set by this strategy (lower than 30% awareness but above 0). It was also checked that the list of links and its associated list of awareness values were coherent with respect to indexes. Finally, checks were also performed to make sure that all links related to the agent performing the action are selected and not all links within the model.

Then for the actual maintenance of the links, it was checked that the right index of the link with the lowest awareness was selected in the list previously established. Then it was checked that the maintenance was duly performed. It was also checked that the affiliation be appropriately taken into account when increasing the awareness level. It was also made sure that if the list of links to maintain is empty, then the code moves to the next possible link maintenance. It was also checked that after each maintenance of a link, the appropriate resources are removed from the agent's resources associated to link maintenance.

For the creation of new links, it was made sure that this is only performed when all active links from the agent concerned are above 30%. Then a check was performed to see that only links with zero awareness within the agent's network be selected for the creation of a new link (new links can only be created between agents that know that they exist hence not selecting awareness -1 links). Similarly to before, it was checked that when creating a link, the appropriate awareness be bestowed upon the new link and the resources be removed from the agent's available maintenance resources. *Looking at the code after implementation, it was found that the wrong equation was used for the creation of new links with the omission of the 0.5 coefficient. This had been added to the Further Work list in Appendix F.*

Finally, for the third step, it was checked that this step be performed only if resources are left through the same while loop as before. It was checked that only links that are below 1 and not equal to -1 in awareness be considered. Similarly to before, checks were performed to make sure that the links be added the right amount of resources depending on the affiliations and the resources. it was also made sure that the resources be removed from the agent's resources after the action is performed. Finally, it was checked that if a link is maintained to a level higher than 1, its awareness be reduced back to 1 (no link is allowed to grow beyond 1 awareness).

For the second strategy, similar checks were performed. The main difference here is the order in which the steps are made and which steps are used. For example, it was checked that the agents must have similar beliefs. For this, it was checked and verified that the agents' aim of the problem be within 0.2 of one another for the three streams theory and the agents' aim of the issue be within 0.2 of one another for all other models. It was checked that the list of links considered is then appropriately formed. Then overall the checks are the same.

**Policy formulation** For the policy formulation, the checks are similar to the checks of the agenda setting process and the strategies are identical. The main difference arose in the second strategy and the definition of similar beliefs. Checks were performed to make sure that the similar beliefs relate to the issue or problem on the agenda in each cases. The rest of the code that was used was the same as the one for the agenda setting process.

### E.2.2. External parties actions [Backbone/Backbone+/ACF]

The external parties can perform two actions and these actions are different in the agenda setting process and the policy formulation process. They are also different in the three streams theory as there a policy and a problem can be present. The resources for the external parties are split in two: 50% for the blanket framing and 50% for the electorate influence. The verifications performed are shown here.

**Blanket framing (AS)** The first checks performed for the blanket framing relate to the causal relations. Not all causal relations can be used for framing but only the ones related to the issue selected by the external party, It was therefore checked that the right causal relations are being selected. Then it was checked that the while loop used to make sure that the agent has enough resources does indeed work. Then for the grading of the actions, it was checked that the actions are graded appropriately based on the equations in the formalisation. It was also made sure that in case there is no partial knowledge, the partial knowledge be set to 0 so that calculations can be performed. It was checked that this be temporary and the None partial knowledge be re-applied after the action has been graded.

For the assessment of the list of grades, it was checked that the right action is selected by checking the grades through a print command. Then it was checked that the action is appropriately applied to the right agent. For this several checks were performed by changing the number of agents manually and the number of causal relations. It was extensively cross checked with the number of grade recorded on in the lists of actions. Note that through this check, it was found several times that the actions performed were the wrong influence on the wrong agents. This has now been fixed. Finally, it was also checked that the resources be removed properly from the agent's available resources for blanket framing actions.

**Electorate influence (AS)** For the electorate influence, the actions are performed differently. This is because the new preference of the electorates is calculated used to obtain the grade. This required the copy of some of the data to have temporary changes in the beliefs of the electorates. This was extensively checked as it is known that copy functions can lead to issue with the reference to memory. It was therefore made sure that copying the data did not have an impact on the rest of the simulation later on. Associated with this action, the preference calculation of the electorate was also verified. This was done similarly to how the verification of the preference calculations of the other agent is performed. This is because the code is mostly the same, simply adjusted for the electorate. It was also checked that the grades assigned are the appropriate ones and that they are stored in the right order.

Finally, similarly to the blanket framing, the implementation of the actions was checked several times. This was once again done to make sure that the right action is applied on the right electorate. Furthermore, it was checked that the right amount of resources are removed from the agent's resources after each implementation of an action.

**Blanket framing (PF)** The main difference between the agenda setting and the policy formulation is the choice of causal relations. This was therefore implemented and checked to make sure that the actions are now performed on the causal relations related to the agenda chosen by the actors. Considering most of the code was re-used from the previous agenda setting section, the checks performed were then the same.

**Electorate influence (PF)** This is similar for the electorate influence. The only difference between agenda setting and policy formulation is related to the issues that are being influenced. The other checks were the same as the ones presented before.

### E.2.3. External parties actions [3S]

For the three streams theory, most of the code was changed. This is because the agents are not using issues anymore but they are using a policy or a problem. Therefore, although the code infrastructure remains the same, most of the code had to be rewritten. Checks were used to make sure that the agents are performing the actions based on their initial choices between problem and policy. The same checks where then performed as previously. For the problem, the choice of causal relations were checked while for the policies, the choice of impact of the policies was checked. The equations to calculate the grade of each of the actions and the implementation of the actions were also checked. This is valid for both the agenda setting process and the policy formulation process.

### E.2.4. Policy makers and entrepreneurs actions [Backbone/Backbone+/ACF]

The actions of the policy entrepreneurs and policy makers are exactly the same. They are constructed in a similar fashion to the actions of the external parties. The main differences are the types of actions that are available to them. This is outlined here.

**Agenda setting** There are three type of actions that the actors can perform: framing, state influence and aim influence. All of these actions are assessed at the same time and the grades are compiled into a long list. This is done for each agent. Once the list has been complied, the action with the highest grade is selected and it is implemented. The list length is therefore the number of causal relations plus two times the amount of agents that are connected to the agent performing the actions and which have an awareness higher than 0. The first verification is performed on the creation of this grade list. It is made sure that only the appropriate are considered for actions. Then it is checked that all actions grades are obtained appropriately. The checks are mostly important for the temporary assignment of the value 0 when no partial knowledge is present in the agent's belief hierarchy. This has shown to cause memory assignment issues in the past.

Then comes the part where the best action is selected. It easy to select the action by simply finding the minimum grade. It is however trickier to define what action that is and on which agent. This was therefore verified after it was found that the wrong actions were selected.

Then there is implementation of the actions. Depending on the action selected the action is implemented on specific actors. The equations here are mostly the same as the ones used for the assessment of the grade. The main different is the use of actual belief and not the partial beliefs anymore. The actions were thoroughly checked to make sure the right outcome is produced. A check in the code is also added to make sure that no beliefs goes above one or below minus one.

**Policy formulation** For the policy formulation, the steps are broadly the same. The main difference here relates in which issues are chosen and which causal relations are chosen. Once that is verified, the rest of the code is broadly the same and the verification checks used are also the same.

### E.2.5. Policy makers and entrepreneurs actions [3S]

Similarly to the addition for the external parties, the addition from the three streams model to the actions of the policy makers and policy entrepreneurs are significant. They required the writing of an entire new code but based using the infrastructure of the other models. The actions related to the problem are mostly the same as the one for the other models. The verification procedure is therefore the same. The main issue there was to identify the right indexes in the belief hierarchies of the actors as the notation is different between problem and issue.

For the policy, an entirely new code has to be put in place. It provides the same state and aim influence actions but a completely new impact framing action that had to be verified to make sure that the impact is calculated appropriately.

Beyond these changes, the rest of the code is very similar in architecture. The grades are placed in a list (different for the problem and the policy) and the lowest grade is the one selected to be implemented. Then it becomes a question of finding out what exactly that action was and to implement it on the right actor.

Checks were performed throughout the code (and the infrastructure is still there). This was done through print functions and in some case where the grade list was complex, by manually checking that the right grade is being applied.

## E.3. The team algorithms

The creation of the team follows a complex algorithms that is outlined in the formalisation. This part of the code was the most challenging one as it dives deep into the object oriented part of the implementation mixed with the lists in which most of the objects are being stored. Groups are formed both in the agenda setting and policy formulation processes. Agents can only be in one group in each of the processes.

### E.3.1. Agenda setting

The team algorithm is a long process of steps that the agent has to go through to see if he can join a team, create a team or leave a team.

The first step is to check if the agent has a team and if so to calculate its belonging level. This belonging level is calculated in a specific function that is used throughout the code. This function was checked to make sure that the belonging level is calculated appropriately. This was done by first checking that the same issue is selected by all agents considered. Then the average belief calculated was checked to make sure it adds up. Finally, it was checked that the belonging level calculated from this average is appropriately placed within the agent's attributes.

The second step simple checks whether an agent has enough belonging level to remain in the team or not. If that agent is the leader then the team would have to be disbanded. This was checked by assigning belonging levels lower than 30% to agents to see whether the code worked.

The third step consists of checking whether the agent meets the requirement to be part of the team (if s/he is in a team). Two cases must be distinguished there with the agent being checked being the leader or just being a member. If the agent is the leader and s/he does not belong in the team anymore, the team must be disbanded. If s/he is just a member, then s/he only needs to be removed from the team member list. Throughout the verification of this step, issues arose. The problem was found to be related to the way an agent is removed from the member list. This lead to memory assignment issues within the list members and the code would crash. This has now been fixed and the members are appropriately removed. When a team is disbanded, it is not deleted, it is just removed from the attributes of the agents that were in that team. The main reason to keep the team is for records keeping. This was checked carefully to make sure that the data can be saved when it is collected.

The check of the beliefs is done along two lines depending on whether the team is a problem team or a policy team. The verification here focused on checking that the appropriate equations are being used and the appropriate indexes in the belief hierarchies are selected. In some instances, it was found that the indexes were and this has since been corrected.

After removal of an agent, then the belonging level has to be recalculated. This was checked to make sure that the belonging level of all agents present in the team are upgraded according to the new level.

The fourth step is to check, if the agent is not in a team, whether the agent can join a team that already exists. The verification here is mostly the same as previously as the requirements are the same. The verification was focused on making sure that the right issues are selected depending on whether the agent is looking at a policy or problem team. And the indexes used were also checked to make sure the right issue is selected.

Finally, the fifth and last step is the creation of a team if the agent still has no team. Again, the requirements here are similar to the ones previously outlined and so is the verification. Additional steps were taken to verify that the resources used are appropriately removed from the agent's attributes. It was also made sure that the appropriate beliefs are used for the creation of the teams as for the first step, partial knowledge is used while for the actual creation check the full beliefs are used. Finally, and this is a big part of the creation of the team, it was checked that overtime there is a contact between agents they provided one another with their beliefs. This was checked and for each of the interactions, there was a check to make sure that the partial knowledge cannot be above one or below minus one.

Checks were also performed on the creation of the teams themselves. It was made sure that the teams are added to the overall list of teams. It was checked that each of the agents considered were added to the list of members in the team. It was made sure that all agents that are part of the team have their attributes updated accordingly and their belonging level checked.

Upon the creation of a team, a shadow network is created. This is in effect the policy network of the team which is created from the network of the team's members. This shadow network created a number of problem as it required the creation of an entirely new network several times leading to a large amount of links. Each of these networks were then stored into arrays associated with the team. This shadow network creation was checked to make sure the right amount of links were added and that they were provided with the correct awareness levels.

Note that these checks were performed for both strategies that are used to create new teams. The checks were fairly similar as the code infrastructure was the same.

### E.3.2. Policy formulation

For the policy formulation, the architecture of the code is mostly the same. The verification steps were therefore similar. The main difference as mentioned previously is the change of issues being considered. This was checked thoroughly to make sure the right issues are addressed at this level of the model.

## E.4. The coalition algorithms

The coalitions are created following what is outlined in the formalisation. The first problem here is to make sure that the right future coalition leader is being chosen. This is particularly important when one coalition has already been created. The agents must not already be in another coalition so the total amount of awareness needs to be recalculated. This was checked to make sure that no agent is found in more than one coalition at a time.

Then the issue is to check that that the right agents are considered to be inserted in a coalition. This is defined based on the beliefs and based on the policy networks of the lead agent. This is again a question of checking the indexes in such a way that the proper issues are considered by the team leader.

The main difference between the agenda setting and the policy formulation processes is that the issue around which the coalitions are created are different. It was therefore important to check that the right issue is being considered in both cases.

Checks were also performed on the fact that the coalition must be placed in the coalition list so that it can be recorded. It was also important to check that the agents attributes are appropriately changed when they join a coalition. Finally, it was important to check that the creation of coalition stop at the right amount (in this case less than 10% of the actors are coalition-less).

## E.5. The teams actions selection and grading

The actions of the teams are split in two parts: the intra-team actions and the inter-team actions. As mentioned previously in the formalisation, the former are about framing actions within the teams while the latter about actions from the teams on outside agents. These are therefore two very different parts of the code.

The actions were mostly verified in the same way as the actions of the agents. The main difference here was for the inter-team actions which were performed by all actors within the team onto all actors that are within the policy network of the team. This sometimes resulted in hundreds of actions being assessed. It was therefore paramount to rightly pinpoint the right actions, who performed it, onto who and about which issue. This was checked through a multitude print function which are still present in the code. Furthermore, a big problem here was the notation system of Python that considers that the first entry in a list is numbered 0. This leads to multiple attempts were the wrong index was selected. Ultimately, this was fixed and it is now provided with certainty that the right actions are performed.

## E.6. The coalitions actions selection and grading

Similarly to the team actions, the coalition actions are modelled on the individual agent actions. They were therefore verified in the same way. The coalition action are much simpler as they are performed by the coalition leader. This reduced the number of actions considered drastically and made it easier to pinpoint which actions should be implemented.

## E.7. The awareness decay

The awareness decay is applied at the end of the tick. This was checked by changing the value of decay to this if it works properly. Furthermore, it was checked that the awareness decay pause that is established after an action has been performed worked appropriately. This was done by changing the amount of time after which the awareness decay is paused.

## E.8. The initialisation

For the initialisation, all of the inputs that are specified by the modeller are placed into a dictionary. This is then transmitted through the function and classes. To verify this dictionary, each of its entries are checked in the main class from which the model is run and all of its contents are re-assigned to the actual parameters from the model. This dictionary was used to simplify the transmission of the inputs from the initialisation file to the main file. Note that this approach can be used for any future case study.

The initialisation is also a large file that constitutes the first list of agents present in the model and the policy network. This was all checked by using print function to make sure that the right amount of resources are added or that the right links are created. Furthermore, checks are in place to make sure that the initialised beliefs of all the agents are below one and above minus one.

## E.9. The data collection

The data collection is a complex process that uses the architecture of the code used by Project Mesa. The original code used deep copy everywhere to appropriately copy the data into new data framed. However, this takes a very large amount of times within the model implemented (upwards of 4 hours per tick for larger models). It was therefore to change the deep copy approach to a simpler approach using copy.copy. This lead to different problems such as memory assignment issues. Ultimately, it was settled to have a mix of deep copy and copy.copy throughout the code. This was intensely verified to make sure that there are no more memory assignment issues.

# F

# Further Work

This appendix presents the list of items that has been thought of for further work.

This first list describes the actions that would be required to have a more complete model.

1. Use the appropriate equation for the creation of new policy network links (currently the 0.5 coefficient is missing).
2. Fix of the formalisation for the awareness decay in the case of team and coalition actions.
3. The implementation of the new formalisation
4. The formalisation of the policy broker concept and its implementation.
5. The implementation of the diffusion theory.
6. The implementation of the feedback theory.
7. The implementation of the external party issue selectiveness mentioned in the conceptualisation.
8. The testing of different partial belief hierarchies initialisation methods.
9. The introduction of full knowledge at the principle belief level.
10. The adaption of the code to allow for more or less than three affiliations.
11. The addition of the infrastructure to be able to save what actions are performed by who, with what impact and whom.
12. Provide an analysis of the policy hierarchy results from the three streams model.
13. Introduce a case study and attempt to find a consistent way of designing the connection between the world and policy emergence model along with appropriate initialisation of the policy network.
14. Perform a more complete and consistent experimentation set along with a broader analysis of the results.
15. Introduce a difference between technical and non-technical issues. According to the literature (Nohrstedt and Weible, 2010), this can be important. Actors are more likely to agree on technical issues and disagree on non-technical issues.

This second list describes some extensions or some further work that could be needed to extend the model:

1. Introduce the possibility to have instruments that have an impact over time. This would require the addition of the possibility to grade these instruments against one time impact instruments.

2. The introduction of a policy package tool. This could be an extension where the agents can create their own policy instruments or an extension that uses current models that build policy instruments (there would then only be a need to connect both models).
3. To enrich the model, it could be possible to introduced the three types of subsystem behaviour mentioned in the literature (Nohrstedt and Weible, 2010; Weible, 2008). These are the unitary subsystem, the collaborative subsystem and the adversarial subsystem. The introduction of such differences could affect the behaviour algorithms of the different actors or change specific weights of specific actions within the actors' algorithms.
4. Construct an in-browser live visualisation.
5. Provide a in-browser GUI for the initialisation of the model.

# G

# Policy Making Theories Concepts

This appendix is a summary of all of the concepts that are mentioned within the theories. It includes their corresponding concepts within the model created in this thesis. When there is no relation, then the concept has not yet been addressed and is therefore not mentioned in the table. Note that a third column is added to signify the policy making theories concepts that have been addressed in the conceptualisation and formalisation but are not yet present within the code.

The concepts with an asterisk are detailed further after the table.

| Policy making theories concept | Model | Concep. |
|---|---|---|
| The three streams theory | | |
| Fluid participation | ✓ | ✓ |
| Problem preferences | ✓ | ✓ |
| Unclear technology | ✗ | ✗ |
| Policy stream | ✓ | ✓ |
| Value acceptability* | ✓ | ✓ |
| Technical feasibility* | ✓ | ✓ |
| Integration of the instrument | ✗ | ✗ |
| Problem stream | ✓ | ✓ |
| Indicators * | ✓ | ✓ |
| Focusing event | ✗ | ✗ |
| Feedback* | ✓ | ✓ |
| Load | ✓ | ✓ |
| Politics stream | ✓ | ✓ |
| Policy makers | ✓ | ✓ |
| Policy entrepreneurs | ✓ | ✓ |
| Policy entrepreneurs time constraints | ✓ | ✓ |
| Policy window | ✓ | ✓ |
| Team creation criteria | ✓ | ✓ |
| Leading by example | ✗ | ✗ |
| Independent streams | ✓ | ✓ |
| The advocacy framework coalition | | |
| Subsystem | ✓ | ✓ |

| | | |
|---|---|---|
| Coalitions | ✓ | ✓ |
| Coalitons influence policy makers | ✓ | ✓ |
| Devil shift | ✗ | ✗ |
| Limited amount of information | ✓ | ✓ |
| Deep core beliefs* | ✓ | ✓ |
| Policy core beliefs | ✓ | ✓ |
| Secondary beliefs | ✓ | ✓ |
| Stable coalitions | ✓ | ✓ |
| Actors show substantial consensus | ✓ | ✓ |
| Secondary before policy core* | ✗ | ✗ |
| Bounded rationality* | ✓ | ✓ |
| Belief system | ✓ | ✓ |
| Coalitions creation criteria | ✓ | ✓ |
| External event | ✓ | ✓ |
| Internal subsystem event | ✗ | ✗ |
| Negotiated agreement | ✗ | ✗ |
| Policy-oriented learning | ✓ | ✓ |
| Policy learning is more likely with moderate level of conflicts | ✓ | ✓ |
| Learning is more likely in a prestigious forum* | ✓ | ✓ |
| Quantitative problems are more conducive to policy learning* | ✗ | ✗ |
| Problems involving natural systems are more conducive to policy learning | ✗ | ✗ |
| Accumulation of technical information does not change the view of opposing coalitions | ✗ | ✗ |
| Administrative agencies advocate for more moderate measures * | ✓ | ✓ |
| Actors within purposive groups are more constrained in their expression beliefs and policy positions than actors from material groups | ✗ | ✗ |
| The diffusion theory | | |
| Leaning mechanism | ✓ | ✓ |
| Imitation | ✗ | ✗ |
| Normative pressure | ✓ | ✓ |
| Competition | ✓ | ✓ |
| Coercion | ✓ | ✓ |
| The feedback theory | | |
| Meaning of citizenship | ✓ | ✓ |
| Form of governance | ✗ | ✗ |
| Power of groups | ✓ | ✓ |
| Definition of policy problems | ✓ | ✓ |

| | | |
|---|---|---|
| The resource effect | ✓ | ✓ |
| The interpretive effect | ✓ | ✓ |
| The policy entrepreneurhsip model | | |
| Social acuity | ✓ | ✓ |
| Definition of problems | ✓ | ✓ |
| Policy entrepreneurs should be ready to build teams | ✓ | ✓ |
| Definition of policy problems | ✗ | ✗ |

Notes concerning the concepts in the advocacy framework coalition:

- The bounded rationality concepts: The agents are not introduced within the model with bounded rationality for say. However, because the agents are included within a large set of agents and each of these agents perfom actions, the overall resulting model can be considered to have agents with boudned rationality.
- Value acceptability, technical feasibility, indicators: these two concepts are not part of the model for say, they can however be incorporated by the modeller in the assessment of the impact of the policy instruments as inputs to the model. In future work, they could be dynamically introduced in the model for the policy instruments. In this way, all policy instruments could be influenced by the agents present in the policy arena.
- Focusing event: Focusing events are not part of the model. However, they can be introduced by the modeller through the use of external events. Depending on the design of the external event, it can act as a focusing event leading to changes in the policy emergence process.
- Feedback: Feedback in the sense of the feedback theory has not been implemented (it was conceptualised and formalised). Feedback is however present through the world simulation in the model.
- Deep core beliefs: They are considered as principle beliefs. Additional layers in the belief hierarchy would be needed to see the use of deep core beliefs which is not excluded by the conceptualisation presented here.
- Secondary before policy core: This assumption is not taken into account in the implementation. However, and this was mentioned within the report, it can be introduced easily.
- Learning is more likely in a prestigious forum: This is not present directly in the model but is introduced through external events which provide a boost in awareness to specific agents participating in a forum.
- Administrative agencies advocate for more moderate measures: This is not excluded, it is dependent on the inputs from the modeller.