# Model description

This chapter describes the ABM model. It will use the ODD protocol, developed in 2006 by [Grimm] to standardize the published descriptions of individual-based and agent-based models (ABMs). ODD stands for Overview, Design Concepts and Details, the three main categories of the protocol. The first element, the overview, provides an overview of the overall purpose and structure of the model. Readers very quickly can get an idea of the model’s focus, resolution and complexity. Furthermore, the overview provides a description of the entities and state variables included in the model, as well as the spatial and temporal scales and extents. The second category, design concepts, describes the general concepts underlying the design of the model according to some characteristics of ABMs, though they are stated not to be exclusive. The design concepts can be seen as a kind of checklist to make sure that important model design decision are made consciously and that readers are aware of these decisions. The third element includes three elements (initialisation, input data and submodels) provide the more technical details of the model, that were omitted in the overview [Grimm both articles]. An overview of the ODD protocol is displayed in Table 1.

Table 1: ODD protocol [Grimm]

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| --- | --- |
|  |  |
| Overview | 1. Purpose 2. Entities, state variables, and scales 3. Process overview and scheduling |
| Design concepts | 1. Design concepts  * Basic principles * Emergence * Adaptation * Objectives * Learning * Prediction * Sensing * Interaction * Stochasticity * Collectives * Observation |
| Details | 1. Initialisation 2. Input data 3. Submodels |

## Purpose

The model aims to describe the possible pathways of society’s response to climate change. In order to do so, the model needs to integrate the energy, climate and economy system with elements of society’s behaviour. The aim is not to provide a perfect and detailed description of the real world energy, economy and climate system; this would be unrealistic and almost insoluble. A trade-off needs to be made between model complexity and model usefulness. The model needs to be complex enough to provide meaningful insights, but simple enough to provide these insights in a reasonable modelling time.

The aim is to investigate if a plausible set of internally consistent assumptions can be translated into understandable and plausible narratives on the possible pathways of society’s response to climate change. This will be done by modelling artificial, interacting heterogeneous agents performing adaptive behaviour in order to explore behavioural patterns in an uncertain evolving world.

Specifically, the model aims to investigate the effect of heterogeneous awareness among society on the need to respond to climate change and the form of mitigation coordination ranging from a global intervention to self-organisation in the form of polycentric cooperation.

## Entities, state variables, and scales

The questions that need to be answered in this section are:What kinds of entities are in the model? By what state variables, or attributes, are these entities characterized? What are the temporal and spatial resolutions and extents of the model?

### Agents and their state variables

The model consists of governments and their populations. The modeller can choose how many governments and how many citizens to include. The total amount of citizens is evenly divided over the amount of governments. The countries can differ by assigning their citizens certain awareness for the future impact of climate change.

Citizens are able to influence governments by expressing their political preference by means of voting. Governments can influence their citizens by enforcing mitigation measures. Citizens do not interact, but governments interact in the form of international climate change negotiations.

|  |  |
| --- | --- |
| Citizens | |
| State variable | **Description** |
| Countrycode | The country code of a citizen describes to which government it belongs. This is used to form a link between the citizen and the government, through which interaction can take place. Furthermore, it can be used to assign a vision, which can be made specific per country. |
| Vision | The fact that people discount future costs and benefits is simplified in this model, to the essence of how far in the future people are able to assess the impact of the expected cumulative GHG emissions. The vision of an agent describes the amount of years that the citizens is able to analyse the future. Since the model runs from 2000 to 2100, this can range from 0 to 100 years. A person that has a vision of 80 years is able to assess the impact of the expected GHG emissions by extrapolating the rate of emitting GHG at that moment in time for 80 years in the future. |
| ExpectedBAUemission | The expected business as usual emission (ExpectedBAUemission) follows from the vision of the citizen, indicating an expected emission at a certain moment in time, by extrapolating current emissions to the future. |
| CCawareness | The climate change awareness (CCawarenss) indicates the awareness of the citizen about the expected impact of climate change resulting in a willingness to reduce current emissions. |
| Emission | **Not explicitly specified in the model but should be.** |

|  |  |
| --- | --- |
| Citizens | |
| State variable | **Description** |
| Countrycode | The country code of a government is the identity of the government. The country code is used to form a link between the citizen and the government, through which interaction can take place. Furthermore, it can be used to assign a vision to the citizens of a government, which can be made specific per country. |
| Political preference | The political preference of a government follows from the average climate change awareness of the citizens of a government. The political preference of a model translates into national mitigation actions a government takes, and is used as a governments opinion about the required response to climate change in international negotiations. |
| Emission | **Not explicitly specified in the model but should be.** |

### Spatial units

The model does not have a special character.

### Environment

#### Climate change impact graph

The assumption that is taken in the model is that the impact of climate change increases exponentially as a function of the cumulative GHG emissions. Agents assess the impact of climate change by their expectations of future emissions and translate this awareness into mitigating change climate change by reducing their emissions. The impact of climate change ranges is captured in a value from 0 to 1. An agent that assesses the impact of climate change with a value of 1 reduces its initial emission with 100%. The relation between the cumulative GHG emissions and the impact of climate change can be adjusted, but the initial settings state that the impact of climate change has a value of 1 in the year 2100 with a cumulative GHG emission by the emission rate of the year 2000.

#### National emission vs. individual emissions

The model holds the assumption that there is a difference between mitigation actions that can be taken by individuals and mitigation actions that can be taken by governments. Individuals have the power to insulate their houses or put a PV panel on the top of the roof, but they cannot directly change the electricity system. These kinds of mitigation actions require subsidies or regulation by the government to (make the market) change the system and are therefore called national emissions. Individuals are only indirectly able to change national emissions by expressing their political preference to means of voting. The percentage of emissions that individuals are able to directly influence can be determined in the model settings.

### Spatial and temporal scales and extents

The model is running over a period of 100 years, with a time-step of a year. To increase the easy of understanding the model and to validate the model, the model is set to run from the year 2000 to the year 2100.

The visualisation of the model displays how the citizens are connected to their governments and how the governments are connected to perform international negotiations. This is for mere visualisation, as the model does not have spatial characteristics.

## Process overview and scheduling

### Narrative

Every tick the following processes are performed:

1. The business as usual emission is determined
2. Citizens determine their own expected business as usual emission, depending on their vision
3. Citizens determine their climate change awareness, depending on their expected business as usual emission
4. Governments determine their political preference
5. Citizens and governments emit GHG

Every predetermined amount of years the following process is performed:

1. Governments participate in international negotiations
2. **The business as usual emission is determined**

The business as usual emission is determined by summing the current emission levels of citizens and governments for the year 2100. This value will be added to the cumulative GHG emission thus far. This calculation is needed for the personal expected business as usual calculation of citizens, depending on the vision of a citizen. The reason is that this calculation requires information from both the citizens as well as the governments, whereas the expected business as usual emission calculation is only performed by citizens.

1. **Citizens determine their own expected business as usual emission, depending on their vision**

Citizens are characterised by a certain vision. This vision states how far in the future a citizen is able to assess the impact of climate change at the current rate of emissions. If a citizen has a vision of 40 years in the year 2020, it will assess the expected cumulative emission in the year 2060 at the current rate of emissions. If the current rate of emissions is 90 per year, and the cumulative GHG emission thus far is 2000, the expected business as usual emission of the citizen is 5600 (90\*40 + 2000). If the vision exceeds the year 2100, the value will be limited to the expected business as usual emission in 2100.

1. **Citizens determine their climate change awareness, depending on their expected business as usual emission**

At the initialisation of the model run a graph is constructed displaying the impact of climate change as a function of the cumulative GHG emissions. The impact of climate change ranges is captured in a value from 0 to 1. An agent that assesses the impact of climate change with a value of 1 reduces its initial emission with 100%. The relation between the cumulative GHG emissions and the impact of climate change can be adjusted, but the initial settings state that the impact of climate change has a value of 1 in the year 2100 with a cumulative GHG emission by the emission rate of the year 2000. This is an exponential function, implying that the impact of climate change increases more rapidly when the cumulative GHG emissions increase.

The citizens use the graph by assessing the impact of climate change according to their expected cumulative GHG emission, the cumulative emission at the current rate of emissions at a moment in time depending on the vision of the citizen.

1. **Governments determine their political preference**

**Governments determine their political preference by**

1. **Citizens and governments emit GHG**

The standard emission of a citizen is 1, and the climate change awareness of a citizen determines the percentage to which this emission is reduced. The standard emission of a government is depending on the amount of citizens it has and the ratio of national emissions versus individual emissions. If 40% of the emissions can be directly influenced by individuals, 60% are national emissions. If a government has 100 citizens, the emission of the government will be 100 / 0.40 – 100 = 150.

The climate change awareness of a citizen result in an emission reduction percentage of that the citizen is willing to reduce by taking mitigation measures. As the emission of a citizen is 1 per year, a climate change awareness of 40% results in an emission of 0.60 per year. The same applies to the emission of a government, depending on the political preference of the government. If a government has an emission of 150, with a political preference of 20% the emission will be 30.

1. **Governments participate in international negotiations**

Every period of a predetermined amount of years, let’s say, every ten years the governments in the model are having international negotiations regarding climate change response. A successful negotiation results in a top-down enforcement of mitigation actions.

The success of these negotiations is determined by several factors. The public opinion on the matter is the main driver for the outcome of the negotiations. If the public opinion asks for mitigation initiatives, the chance for a successful outcome increases. The second determinant for a successful outcome is related to the differences in opinions on the matter between the countries involved in the negotiations. Larger differences between countries decrease the chance for a successful outcome, due to prisoner dilemma-like situations [Putnam]. A final indicator for the success of international negotiations is chance. Negotiations can be affected by the actions of a strong leader, good temporary economic situations, and a positive media campaign etcetera.

1. The public opinion among citizens of the participating governments

The shared public opinion will be the average of the national climate change awareness factors.

If three governments participate in the negotiations, and government A has a climate change awareness of 0.20, government B 0.30, government C 0.70, the shared public opinion is: 0.20 + 0.30 + 0.70 / 3 = 0.40.

1. Differences in opinion between government

The difference in opinion is determined by the difference between the government with the highest climate change awareness and the government with the lowest climate change awareness.

Using the previous example this would be: 0.70 – 0.20 = 0.50

1. Chance

The two previous indicators increase and decrease respectively the chance for a successful outcome of the international negotiations. The importance of these indicators can be set in the model. The base options are a multiplication factor of 1 for the shared opinion and a multiplication factor of 0.25 for the difference in opinion.

Using the previous example, this would result in the following chance for a successful negotiation: 0.40 \* 1 – 0.50 \* 0.25 = 0.285.

If the outcome of an international negotiation turns out to be successful, depending on the chance for a successful negotiation, governments enforce mitigation actions to themselves and their citizens. This implies specifically that they increase the emission reduction percentage. The effect of this enforcement on national emissions and individual emission can be changed.

### Pseudo-code

[Code]

## Design concepts

### Basic principles

The basic principles underlying this model’s design are the following:

#### Integrating the energy, climate and economy system with behavioural aspects of society

The model assumes that the energy, climate and economy system are connected, and that society adapts itself to the state of these systems. The energy system is represented by the fact that citizens and governments have GHG emissions, influencing the climate system due to the relation between GHG emissions and climate change impact. Citizens in society assess the expected climate change impact to reduce their current emissions, simplifying the economic considerations of an agent to mitigate climate change, in combination with a time preference.

#### Heterogeneous climate change awareness

The model assumes that the awareness of the expected future impact of climate change is different per agent, in the case of the model characterised per country with a slight variance using a normal distribution.

#### Response to climate change occurs by means of top-down enforcement as well as self-organisation of individual mitigation actions.

The model assumes that society’s response to climate change can be caught in two levels: at the international and national level of governments, but also arising from individual initiatives of citizens. These two forms of response are also able to influence each other: large climate change awareness among the citizens of a country influence the political preference of a country, and therefore indirectly national mitigation actions and the opinion of the government in international negotiations.

#### Relation between complexity of model and the purpose of the model

The model aims to provide more insights into the effects of these basic principles. The model design is therefore based on these principles. The model is simplified in order to reduce the complexity of the model and still fit the purpose of the model.

### Emergence

The most important model outcome is the cumulative GHG emissions, as this is an indication for the severity of climate change. The cumulative GHG emissions result from the mitigation measures taken by citizens and governments over time. This can mainly vary due to two characteristics of the model. The first relates to the differences in visions of citizens that affect the climate change awareness of the citizens and therefore the emission reduction. A second important factor influencing the cumulative GHG emissions is the success or failure of international negotiations, resulting in top-down enforcement of mitigation actions.

Other interesting model outcomes are the annually GHG emission reductions, the average climate change awareness, and political preference of governments.

### Adaptation

Citizens adapt their emission to the expected impact of climate change due to expected cumulative GHG emissions. A citizen asks itself the question: ‘if emissions are continuing like this, do I need to reduce my current emission profile, in order to contribute to the mitigation of climate change impact?’ The adaptive behaviour therefore is an explicit decision based on a citizen’s perception of the need to act.

Governments adapt their emission to the opinion on the matter of their citizens as the average climate change awareness of its citizens determines the political preference of the country and therefore the percentage emission reduction.

### Objectives

Since citizens change their emission level based on their expected impact of climate change due to expected cumulative GHG emissions, it can be stated that citizens aim to fulfil a certain objective. It can be stated that citizens aim to reduce their emission profile in a way that seems to fit with their expectation of the future impact of climate change.

Governments aim to fulfil the expectations of its citizens by adapting its emission according to the average climate change awareness of its citizens.

### Learning

Agents in the model do not change their adaptive traits over time due to learning.

*[Maybe governments are able to increase the vision of its citizens by campaigns; maybe governments increase their own vision due to investments in R&D?]*

### Prediction

Citizens in the model predict future environmental conditions, by estimating the future cumulative GHG emissions and accordingly the expected climate change impact related to that cumulative GHG emission level. The citizen predicts the future cumulative GHG emissions at a certain moment in time, depending on the vision of the citizen, at the current rate of emissions. The prediction is therefore imperfect because a citizen does not incorporate the fact that other agents as well as itself are likely to respond according to the prediction, which causes the prediction to become false.

### Sensing

Citizens are assumed to sense the current global emission level. This implies that citizens are aware of and have perfect information of the global GHG emissions. The model is designed in such a way that the citizens are assumed to know this value, it is not explicitly modelled.

Governments are assumed to sense to political preference of its citizens in terms of the climate change awareness of its citizens. This is depending on the social structure of the model, as governments are linked to their citizens. This social structure does not emerge from the model, but is imposed at the initialisation of the model.

### Interaction

Citizens express their political preference to their governments by means of voting. However, the voting mechanism is simplified to the extent of taking the average of the climate change awareness of the citizens of a government.

Another form of interactions occurs between governments, every predetermined amount of years. This form of interaction is also simplified to the extent that the average political preference of the governments is taken to determine the chance for a successful outcome of the negotiations. A more complicated form of interaction is based on the [Putnam] two level game, which implies that as the differences in political preferences between countries is larger, the chance for a successful outcome of the negotiation decreases. This can be credited to the fact that negotiations become more difficult when they are subject to opposing opinions.

### Stochasticity

Stochasticity in the model occurs in two locations in the model. The first location is the distribution of state variables in the initialisation of the model, as the vision of citizens is distributed using a normal distribution. This is done consciously, in order to introduce heterogeneity of climate change awareness among agents in the model. The second location is regarding the outcome of the international negotiations. The conditions of the negotiations result in a chance for a successful outcome of the negotiation, a number between 0 and 1. This number is then compared with a random number between 0 and 1, which determines whether the negotiation is successful. This is again designed explicitly, because international negotiations are partly subject to chance.

### Collectives

Citizens can be seen as a collective. The political preference of a government assembles as a result of individual climate change awareness of the citizens. However, this collective is already represented by another breed, type of agent in the model, the governments.

### Observation

The main data of interest is the cumulative GHG emissions, as this is the outcome of interest. The most important data point is the final outcome in the model, the year 2100, as this can be used as a point of reference. However, the whole model run data is interesting, as this can show whether the final cumulative GHG emission level is influenced by mitigation enforcement of governments, a steady or rapid decrease in emissions et cetera. Other variables that are observed are therefore the annual GHG emissions, the average climate change awareness among citizens and the chance for successful outcomes of negotiations.

## Initialisation

*Questions: What is the initial state of the model world, i.e., at time t = 0 of a simulation run? In detail, how many entities of what type are there initially, and what are the exact values of their state variables (or how were they set stochastically)? Is initialization always the same, or is it allowed to vary among simulations? Are the initial values chosen arbitrarily or based on data? References to those data should be provided. Explanation: Model results cannot be accurately replicated unless the initial conditions are known. Different models, and different analyses using the same model, can of course depend quite differently on initial conditions. Sometimes the purpose of a model is to analyze consequences of its initial state, and other times modelers try hard to minimize the effect of initial conditions on results.*

In the initialisation of the model, agents are created and their properties are assigned, the frequency and effect of international negotiations is determined, and the shape of the climate change impact graph is designed.

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| --- | --- |
| Variable | Possible setting |
| Number of Governments | 0 - 10 |
| Number of Citizens | 0 – 500 |
| Vision [per country specific] | 0 – 100 |
| Ratio Local Emission National Emission | 0 – 1 |
| Years Between International Negotiations | 0 – 100 |
| Importance Opinion Difference | 0 – 1 |
| Reduction Policy Impact | 0 – 1 |
| Effect International Policy on Individual Emission | 0 - 1 |
| Effect International Policy on National Emission | 0 - 1 |
| Exponential Factor | 1.01 - 2 |
| Impact Factor | 0 - 1 |

## Input data

The model does not use input data to represent time-varying processes.

## Submodels

*Questions: What, in detail, are the submodels that represent the processes listed in ‘Process overview and scheduling’?What are the model parameters, their dimensions, and reference values? How were submodels designed or chosen, and how were they parameterized and then tested?*