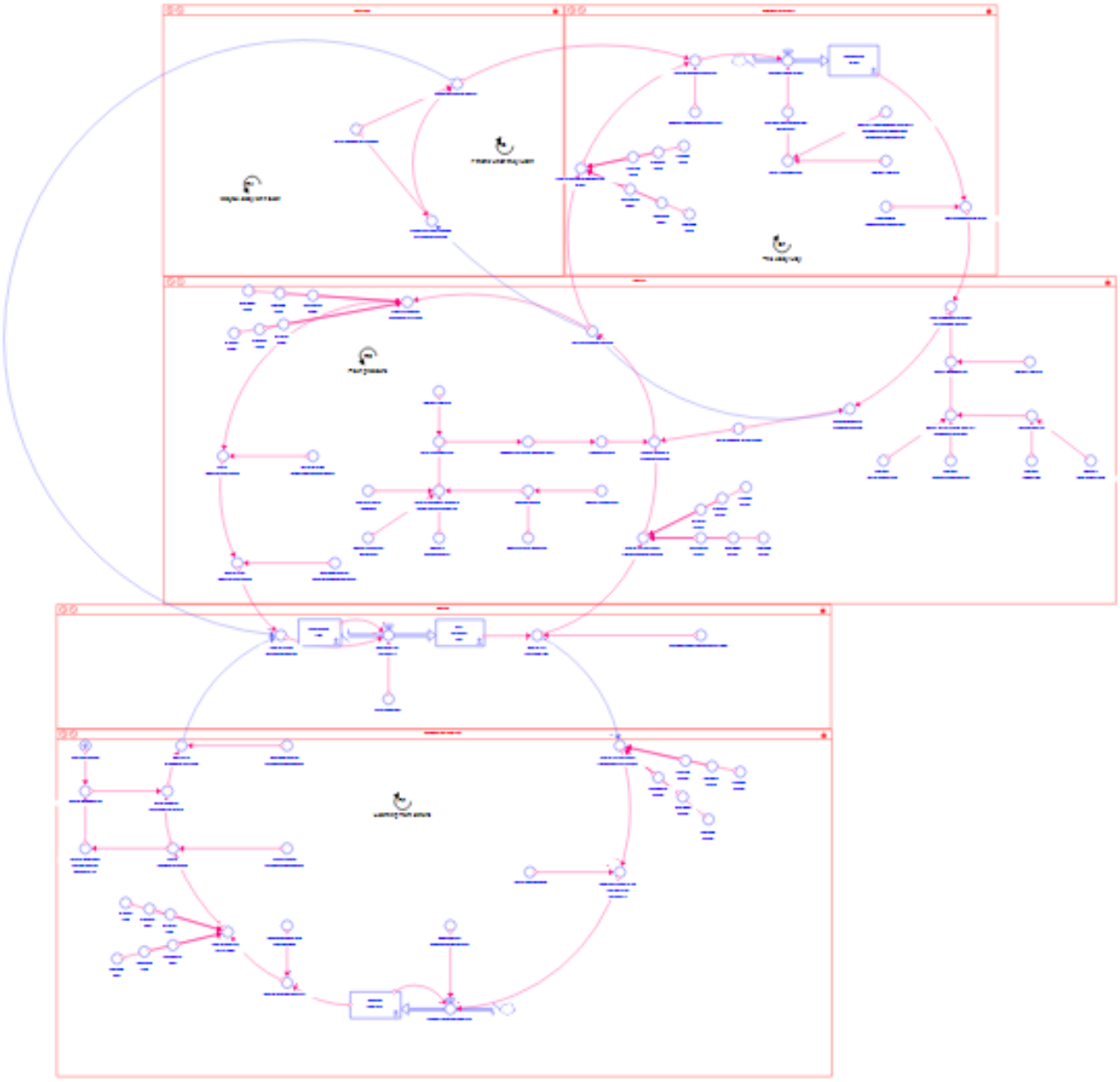
Accelerating the Adoption of True Sustainability

Why Firms Are Delaying Adoption and How We Can Help Them

December, 2024

Appendix A: Stock and Flow diagram



For a clearer overview of the model, please refer to the attached model file.

Appendix B: Documentation

Variable name	Equation	Units	Documentation
Adoption			
Adoption_of_true_sustainability	MIN(IDEAL_ADOPTION*Effect_of_risk_and_resistance_on_adoption, Unsustainable_firms/DT)	Percentage of firms/Years	This flow refers to the flow from Unsustainable firms to Truly Sustainable Firms. The flow represents the percentage of total firms that adopt true sustainability per year. The percentage is determined by the Ideal Adoption multiplied by the risk and resistance effect. While the Adoption per year is not directly dependent on Unsustainable Firms, the flow is controlled by the MIN function to restrict the flow to adopt more firms than possible from the Unsustainable Firms stock. Adoption always takes a positive value, as it is assumed that once firms have adopted true sustainability, they will not change their business core back to unsustainable.
Effect_of_risk_and_resistance_on_adoption	MAX(0, ((Relative_risk_of_remaining_unsustainable-Relative_risk_of_becoming_sustainable)*(1-Change_resistance_to_adoption)))	dmnl	Refers to the extent to which both risks and resistance can affect Adoption. The equation shows the decision that firms will not choose to Adopt when the Relative perceived risk of becoming sustainable is higher than the Relative perceived risk of remaining unsustainable. The higher the total (positive) risk, the higher the Adoption. The equation also takes into consideration the negative, linear effect of Change resistance. The higher the resistance, the lower the Adoption.
IDEAL_ADOPTION	10	Percentage of firms/Years	This parameter refers to the percentage of firms that would adopt true sustainability if the conditions were ideal (Relative perceived risk of remaining unsustainable = 1; Relative perceived risk of becoming sustainable = 0; Change resistance adoption = 0). These conditions allow 100% of firms to adopt true sustainability, with an implementation time of 10 years (J. klein Gebbinck, personal communication).
MAXIMUM_TRULY_SUSTAINABLE_FIRMS	100	Percentage of firms	This value represents the maximum value Truly sustainable firms can take. As the stock amount is visualised in percentage of a whole, the maximum value the stock can take is 100%. The maximum value is needed to normalize the Truly sustainable firms to turn it into an effect on Uncertainty.
Relative_truly_sustainable_firms	Truly_sustainable_firms/MAXIMUM_TRULY_SUSTAINABLE_FIRMS	dmnl	This variable represents the normalized Truly sustainable firms. The normalization is necessary to turn the risk into an effect on Uncertainty.
Truly_sustainable_firms(t)	Truly_sustainable_firms(t - dt) + (Adoption_of_true_sustainability) * dt	Percentage of firms	This stock represents the percentage of all firms that have adopted true sustainability. It is regulated by the inflow of Adoption of true sustainability. The initial value is 5%, as it is assumed that 5% of firms are inherently sustainable, without having to make the transition to true sustainability. Further research on this exact value might make the model more accurate, but does not change the dynamics of the model.

	INIT Truly_sustainable_firms = 5		
Unsustainable_firms(t)	Unsustainable_firms(t - dt) + (- Adoption_of_true_sustainability) * dt INIT Unsustainable_firms = 100- Truly_sustainable_firms	Percentage of firms	This stock represents the percentage of firms that have not adopted true sustainability. The stock is depleted by the flow of Adoption of true sustainability. The initial value is the remaining firms that have not become truly sustainable, thus subtracting the total percentage of firms (100) by the truly sustainable firms (5).
Compensating actions			
ACTIONS_IMPLEMENTATION_DELAY_TIME	4+Policy_1_implementation	Years	This variable represents the number of years it takes to implement one compensating action. It includes the time to formulate the plan, propose it to management, and the time until the action is successfully implemented. The value of 4 is suggested by J. klein Gebbinck.
Compensating_actions(t)	Compensating_actions(t - dt) + (Implementation_of_actions) * dt INIT Compensating_actions = 0	Actions	This stock represents the accumulated number of compensating actions that have been implemented. It is a material stock and is regulated by the inflow of Implementation of actions. The initial value of 0 means that no Compensating actions have been implemented at the beginning of the simulation time. This makes sense as the simulation time starts in 1940, when sustainability was just starting to gain attention (Warde, 2011)
Effect_of_pressure_on_compensating_actions	LOGISTICBOUND(MINIMUM_EPCA, MAXIMUM_EPCA, Relative_stakeholder_pressure, X_MIDDLE_EPCA, STEEPNESS_EPCA, X_START_EPCA, X_FINISH_EPCA)	dmnl	This variable represents the positive (assumed) effect of stakeholder pressure on compensating actions. The equation forms an S-shaped behaviour. As stakeholder pressure initially grows, it will not affect the implementation of compensating actions too much, a little pressure is normal. The more pressure grows, the more compensating actions will be implemented to reduce the pressure. As pressure takes on high values, firms will almost have reached their limit of compensating actions (4). Therefore, extra pressure will not have as much of an effect on compensating actions as the lower values.
Implementation_of_actions	Indicated_compensating_actions/ACTIONS_IMPLEMENTATION_DELAY_TIME	Actions/Years	This inflow represents the number of compensating actions that are implemented per year on average per firm. The value is calculated by dividing the number of compensating actions that should be implemented based on pressure and resistance by the amount of time it takes to implement one action. The more pressure and resistance, the more compensating actions will be implemented.

Indicated_compensating_actions	NORMAL_COMPENSATING_ACTIONS*Effect_of_pressure_on_compensating_actions*Change_resistance_to_adoption	Actions	This variable represents the number of Compensating actions that a firm would implement on average, affected by pressure and resistance. The equation therefore multiplies the Normal compensating actions by the Effect of pressure on compensating actions and by Change resistance to adoption. It is assumed that Change resistance and Indicated compensating actions are related linearly. As there is more pressure, firms will implement more compensating actions in order to reduce the pressure. However, as Compensating actions only have a limited effect, the increase in pressure after the limit has been met will have a negative effect on Change resistance. That is why the equation also includes the multiplication of Change resistance, even if it might seem as if the equation takes Stakeholder pressure into consideration twice. If there was no limit on compensating actions, then multiplying the Normal with Change resistance would not make sense.
MAXIMUM_EPCA	4	dmnl	This variable represents the maximum effect of stakeholder pressure on compensating actions. The value of 4 means that maximum stakeholder pressure (1) has a quadrupling effect on Normal compensating actions. This value is calibrated so that the results fit the reference mode, confirmed by J. klein Gebbinck.
MINIMUM_EPCA	1	dmnl	This value represents the minimum effect of stakeholder pressure on compensating actions. The value of 1 means that no stakeholder pressure (0) will have no effect on the Normal compensating actions (1).
NORMAL_COMPENSATING_ACTIONS	1	Actions	This variable represents the number of Compensating actions that a firm implements on average. The value of 1 has been calibrated so that the results fit the reference mode.
Policy_1_implementation	POLICY_1:_GOVERNMENT_SUBSIDIES_ON_COMPENSATING_ACTIONS:_DECREASE_IN_DELAY_TIME*POLICY_1_SWITCH	Years	Refers to the actual decrease in Actions implementation delay time. If the policy has not been activated, the decrease will be 0. Otherwise, the variable will take the value of -2.
POLICY_1_SWITCH	0	dmnl	This switch between 0 (inactive) and 1 (active) is used for the testing of policy 1.
POLICY_1:_GOVERNMENT_SUBSIDIES_ON_COMPENSATING_ACTIONS:_DECREASE_IN_DELAY_TIME	STEP(-2, 2030)	Years	Refers to the actual decrease in Actions implementation delay time because of the implementation of policy 1. According to J. klein Gebbinck (personal communication), it takes 5 years to draw up the policy and get it approved. Starting from now, a realistic start time would thus be 2030. At the start time, the policy immediately goes into full effect, as it is assumed that all subsidies are given out. Moreover, it is assume that these subsidies decrease the delay time with 2 years.
Relative_compensating_actions	Compensating_actions/THRESHOLD_COMPENSATING_ACTIONS	dmnl	This variable represents the fraction of Compensating actions compared to their threshold. A value < 1 means that the threshold has not been reached. A value of 1 is right at the threshold. A value

			> 1 means that the threshold has been passed. Any value > 1 does not have great significance to the results, as the Effect of compensating actions is limited from a Relative compensating actions value of 1. The Relative compensating actions compares the stock instead of the flow, as it is assumed that stakeholders look at the Compensating actions that are implemented during a longer period of time.
STEEPNESS_EPCA	10	dmnl	The steepness is calibrated to the normal slope of an S-shaped graphical function.
THRESHOLD_COMPENSATING_ACTIONS	25	Actions	This variable represents the maximum number of compensating actions that is accepted by stakeholders to decrease their pressure before the actions are not effective anymore. Compensating actions can only minimize stakeholder pressure temporarily (Shevchenko et al., 2016). Since the actions offset a firm's negative impact, rather than eliminate the negative impact, stakeholders will not accept the implementation of actions after a certain threshold after this realization (Pagell & Shevchenko, 2013). Because of limited time, it is assumed that the Threshold is an exogenously fixed variable. The value has been calibrated to match the reference mode. A higher value means that it takes more Compensating actions before they lose their effect on the Decrease of stakeholder pressure. Future research should endogenize the variable for more accuracy.
X_FINISH_EPCA	1	dmnl	The value of 1 represents the maximum value that Relative stakeholder pressure can take.
X_MIDDLE_EPCA	0.5	dmnl	This value represents the middle of the S-shaped curve. As the curve is symmetrical and ranges between 0 and 1 on the x-axis, a value of 0.5 is appropriate.
X_START_EPCA	0	dmnl	The value of 0 represents the minimum value that Relative stakeholder pressure can take.
Knowledge and uncertainty			
Change_in_perceived_uncertainty	(Uncertainty_brought_by_the_transition_to_true_sustainability-Perceived_uncertainty)/UNCERTAINTY_PERCEPTION_DELAY_TIME	Uncertainty/Years	It takes firms time to perceive the actual uncertainty. This information delay flow is determined by the gap between Uncertainty Brought by the Transition to True Sustainability and Perceived Uncertainty, divided by the time it takes firms to perceive the change in perception. The bigger the gap, the bigger the Change in Perceived Uncertainty.
"Effect_of_truly_sustainable_firms_on_uncertainty_(ETSFU)"	LOGISTICBOUND(MINIMUM_ETSFU, MAXIMUM_ETSFU, Relative_truly_sustainable_firms, X_MIDDLE_ETSFU, STEEPNESS_ETSFU, X_START_ETSFU, X_FINISH_ETSFU)	Dimensionless	This is an assumed effect. The equation represents a Z-shaped effect of the Relative Truly Sustainable Firms on the Uncertainty Brought by the Transition to True Sustainability. The more firms are truly sustainable, the more knowledge there is on how to become sustainable, which also decreases costs of becoming truly sustainable. These effects decrease uncertainty (Durst & Zieba, 2019). Therefore, the Effect of Truly Sustainable Firms on Uncertainty takes a value between 1 (0 number of firms keeps Uncertainty level at the Initial Uncertainty) and 0 (if all firms have

			adopted true sustainability, there is no uncertainty on how to adopt). The effect is Z-shaped (assumed), as a small amount of sustainable firms will not decrease uncertainty too much. It is hard to compare a few cases and the chance that you can replicate a business model because of similarities to yours is low. As more firms become truly sustainable, more practical knowledge can be compared, decreasing uncertainty at a higher rate. When most firms have adopted true sustainability, extra knowledge will not have as big of an impact anymore on uncertainty, decreasing the rate.
"Effect_of_uncertainty_on_risk_(EUR)"	LOGISTICBOUND(MINIMUM_EUR, MAXIMUM_EUR, Relative_perceived_uncertainty, X_MIDDLE_EUR, STEEPNESS_EUR, X_START_EUR, X_FINISH_EUR)	dmnl	The equation represents the S-shaped effect of the relative Perceived Uncertainty on the Risk of Becoming Sustainable. As uncertainty decreases, the risk decreases. No uncertainty (0) eliminates the risk completely (0), while high uncertainty (1), has no effect on the current risk. The effect has an S-shaped effect (assumed), as a decrease in uncertainty does not immediately decrease the risk. The more uncertainty decreases, the lower the risk becomes. As uncertainty is very low, an extra decrease in uncertainty will not have too much effect on the risk.
INITIAL_RISK_OF_BECOMING_SUSTAINABLE	0.5	Risk	This parameter represents the initial value of the risk. The higher the initial value, the less favourable it is to adopt true sustainability, and the more the risk must decrease in order to make firms adopt true sustainability. The initial value is 0.5 (J. klein Gebbinck, personal communication), which means that the risk is actually not too high (on a scale from 0 to 1). Many firms know how to become sustainable, but choosing for Compensating actions is much easier, which is why this loop (R1) will only be activated later in time.
INITIAL_UNCERTAINTY	0.6	Uncertainty	This parameter represents the initial value of the actual uncertainty. The higher the initial value, the less firms know about becoming sustainable (including the high costs that come with learning about sustainability). The initial value is 0.6 (J. klein Gebbinck, personal communication), which means that the uncertainty is actually not extremely high (on a scale from 0 to 1). Firms know enough about sustainability to realize that they need to become more sustainable. However, uncertainty is still rather high, as there are not many examples of true sustainability to follow.
MAXIMUM_ETSFU	0	dmnl	This value represents the maximum effect of Truly sustainable firms on the uncertainty. The value of 1 means that maximum Truly sustainable firms (1) has a negative effect on the uncertainty (0). The more firms adopt true sustainability, the lower the uncertainty. If all firms adopt true sustainability, there will be no more uncertainty, as everyone knows how to become sustainable.
MAXIMUM_EUR	1	dmnl	This value represents the maximum effect of uncertainty on the risk. The value of 1 means that maximum uncertainty (0) has no effect on the risk (1). The risk is only able to decrease, as it is assumed that knowledge on how to become sustainable will not fade (knowledge will remain available). Therefore, uncertainty is not able to increase, thus the risk cannot increase.

MAXIMUM_PERCEIVED_UNCERTAINTY	1	Uncertainty	This value represents the maximum value Perceived uncertainty can take. As Uncertainty is a ratio between 0 and 1, the maximum value is 1. The maximum value is needed to normalize the uncertainty to turn it into an effect on the Risk.
MAXIMUM_RISK_OF_BECOMING_SUSTAINABLE	1	Risk	This value represents the maximum value Risk can take. As Risk is a ratio between 0 and 1, the maximum value is 1. The maximum risk is needed to normalize the Risk to turn it into an effect on Adoption.
MINIMUM_ETSFU	1	dmnl	This value represents the minimum effect of Truly sustainable firms on the uncertainty. The value of 1 means that minimum Truly sustainable firms (0.05) has no effect on the uncertainty (1). The uncertainty is only able to decrease, as it is assumed that knowledge on how to become sustainable will not fade (knowledge will remain available). Therefore, uncertainty is not able to increase, thus the risk cannot increase.
MINIMUM_EUR	0	dmnl	This value represents the minimum effect of uncertainty on the risk. The value of 0 means that no uncertainty (0) eliminates the risk of becoming sustainable (0).
Perceived_uncertainty(t)	Perceived_uncertainty(t - dt) + (Change_in_perceived_uncertainty) * dt INIT Perceived_uncertainty = 1	Uncertainty	This stock represents the perception of how high Uncertainty is regarding the Adoption of True Sustainability. It is an information stock and is regulated by the inflow of Change in Perceived Uncertainty. The stock will adapt to the actual Uncertainty Brought by the Transition to True Sustainability. The initial value of 1 represents the fact that initially firms do not know how high uncertainty is, therefore assuming a value of 1 indicating the maximum uncertainty. As time goes by, firms will get a better understanding of the actual uncertainty and adjust their perception accordingly.
Policy_4_implementation	Policy_4:_Government_subsidies_adoption:_decrease_in_risk*POLICY_4_SWITCH	Risk	Refers to the actual decrease in Risk. If the policy has not been activated, the decrease will be 0. Otherwise, the variable will take a value between initial decrease (0.1) and 0.
POLICY_4_SWITCH	0	dmnl	This switch between 0 (inactive) and 1 (active) is used for the testing of policy 4.
Policy_4:_Government_subsidies_adoption:_decrease_in_risk	STEP(MIN(0.1, Risk_of_becoming_sustainable), 2030)	Risk	Refers to the actual decrease in risk because of the implementation of policy 4. According to J. klein Gebbinck (personal communication), it takes 5 years to draw up the policy and get it approved. Starting from now, a realistic start time would thus be 2030. At the start time, the policy immediately goes into full effect, as it is assumed that all subsidies are given out to unsustainable firms. The government gives out subsidies until the risk is eliminated, showing a decreasing curve as the Risk takes a value below the decrease in risk mandated by the government.
Relative_perceived_uncertainty	Perceived_uncertainty/MAXIMUM_PERCEIVED_UNCERTAINTY	dmnl	This variable represents the normalized Perceived uncertainty. The normalization is necessary to turn the uncertainty into an effect on the Risk.

Relative_risk_of_becoming_sustainable	Risk_of_becoming_sustainable_after_policy_4/MAXIMUM_RISK_OF_BECOMING_SUSTAINABLE	dmnl	This variable represents the normalized Risk of becoming sustainable. The normalization is necessary to turn the risk into an effect on Adoption.
Risk_of_becoming_sustainable	INITIAL_RISK_OF_BECOMING_SUSTAINABLE*"Effect_of_uncertainty_on_risk_(EUR)"	Risk	This variable is by multiplying the initial risk with the effect of uncertainty. The value can only decrease, as it is assumed that knowledge on how to become sustainable will not fade (knowledge will remain available). A high value means that firms could experience lots of problems when adopting true sustainability, while a low value favours the adoption.
Risk_of_becoming_sustainable_after_policy_4	Risk_of_becoming_sustainable-Policy_4_implementation	Risk	This variable represents the value of the Risk after the implementation of Government subsidies. The variable is necessary, as the height of the risk decreased by Government subsidies is dependent on the value of Risk before the implementation. This variable thus avoids a circular connection and can be used to compare the Risk before and after the policy implementation.
STEEPNESS_ETSFU	10	dmnl	The steepness is calibrated to the normal slope of a Z-shaped graphical function.
STEEPNESS_EUR	10	dmnl	The steepness is calibrated to the normal slope of an S-shaped graphical function.
Uncertainty_brought_by_the_transition_to_true_sustainability	INITIAL_UNCERTAINTY*"Effect_of_truly_sustainable_firms_on_uncertainty_(ETSFU)"	Uncertainty	This value refers to the actual uncertainty and is determined by the Initial Uncertainty multiplied by the Effect of Knowledge on Uncertainty. The lower the effect, the lower Uncertainty will be.
UNCERTAINTY_PERCEPTION_DELAY_TIME	4	Years	This refers to the number of years that it takes firms to perceive a change in uncertainty, confirmed by J. klein Gebbinck (personal communication).
X_FINISH_ETSFU	1	dmnl	The value of 1 represents the maximum value that Relative truly sustainable firms can take, as it is a ratio.
X_FINISH_EUR	1	dmnl	The value of 1 represents the maximum value that Perceived uncertainty can take, as it is a ratio.
X_MIDDLE_ETSFU	0.525	dmnl	This value represents the middle of the S-shaped curve. As the curve is symmetrical and ranges between 0.05 and 1 on the x-axis, a value of 0.525 is appropriate.
X_MIDDLE_EUR	0.5	dmnl	This value represents the middle of the S-shaped curve. As the curve is symmetrical and ranges between 0 and 1 on the x-axis, a value of 0.5 is appropriate.
X_START_ETSFU	0.05	dmnl	The value of 0.05 represents the minimum value that Relative truly sustainable firms can take, as it is a ratio, and the initial value of Truly sustainable firms is 5 (out of 100).
X_START_EUR	0	dmnl	The value of 0 represents the minimum value that Perceived uncertainty can take, as it is a ratio.

Pressure			
Absolute_decrease_in_stakeholder_pressure	INITIAL_CHANGE_IN_PRESSURE*Effect_of_compensating_actions_on_stakeholder_pressure	Pressure/years	This variable represents the decrease in stakeholder pressure per year. The value is calculated by multiplying the Normal change in pressure by the Effect of compensating actions. A high value means a great decrease in stakeholder pressure, while 1 means the normal decrease. The variable takes an absolute value, as it is compared with the value of Increase in stakeholder pressure. Not making it absolute could result in a negative value for Relative stakeholder pressure.
Absolute_increase_in_stakeholder_pressure	INITIAL_CHANGE_IN_PRESSURE*Effect_of_truly_sustainable_firms_on_stakeholder_pressure*Exogenous_growth	Pressure/years	This variable represents the increase in stakeholder pressure per year, symbolizing factors such as competitive advantage, awareness, and reputation. The value is calculated by multiplying the Normal change in pressure by the Effect of truly sustainable firms and the by the Exogenous growth. A high value means a great increase in stakeholder pressure, while 1 means the normal increase.
Effect_of_compensating_actions_on_stakeholder_pressure	1+MIN(Relative_compensating_actions, 1)*Policy_2_implementation	dmnl	This variable represents the positive effect of compensating actions on the absolute decrease in stakeholder pressure. The decrease of stakeholder pressure grows linearly to the growth of compensating actions. No compensating actions (0) have no effect on the decrease (1). However, as the threshold has been reached (Relative compensating actions = 1), extra compensating actions will not have further effect on the decrease. The equation uses a MIN function to symbolize this effect: the effect will grow until it reaches a maximum effect of 2. After that, the effect will remain at 2. The equation also includes the effect of Policy 2.
"Effect_of_stakeholder_pressure_on_risk_(ESPR)"	LOGISTICBOUND(MINIMUM_ESPR, MAXIMUM_ESPR, Relative_stakeholder_pressure, X_MIDDLE_ESPR, STEEPNESS_ESPR, X_START_ESPR, X_FINISH_ESPR)	dmnl	This is an assumed effect. The equation represents an S-shaped effect of the Relative Stakeholder Pressure on the Risk of Remaining Unsustainable. With the maximum stakeholder pressure of 1, the Effect can multiply the risk by 3.3, making the risk able reach its maximum of 1. The effect is S-shaped (assumed), as a little pressure will not increase the risk too much, a bit of pressure is normal. The higher the pressure, the more risk firms face. At very high pressure, firms are already facing high risks. Extra pressure, will not increase the risk linearly, decreasing the slope.
Effect_of_truly_sustainable_firms_on_stakeholder_pressure	LOGISTICBOUND(MINIMUM_ETSFS, MAXIMUM_ETSFS, Relative_truly_sustainable_firms, X_MIDDLE_ETSFS, STEEPNESS_ETSFS, X_START_ETSFS, X_FINISH_ETSFS)	dmnl	The equation represents the S-shaped effect of the relative Truly sustainable firms on the Absolute increase in stakeholder pressure. As more firms become truly sustainable, stakeholder pressure increases because of factors such as competitive advantage, awareness and reputation. If all firms are truly sustainable, pressure increase will be doubled. The effect has an S-shaped effect (assumed), as a small initial increase in Truly sustainable firms might go unnoticed by stakeholders, thus having a limited effect on the pressure. As more firms adopt true sustainability, more stakeholders will notice and pressure increases. At a high level of Truly sustainable firms, most stakeholders will have already increased their pressure, making the effect of the last few firms becoming truly sustainable less significant than before.

Exogenous_growth	EXP(NORMAL_PRESSURE_CHANGE_RATE*(TIME-STARTTIME))	dmnl	This variable represents the exponential growth of stakeholder pressure. Stakeholder pressure is growing over time because of more exposure to events such as climate change disasters, research findings on climate change, and decreasing life conditions due to climate change (Baiardi & Morana, 2020). Since these factors are not influenced by the system that is modelled, they are represented as an exogenous variable. Future research could explore the systemic effects of this kind of stakeholder pressure. While Baiardi and Morana (2020) suggest that the growth is S-shaped, the growth is modelled in this paper as exponential due to skill and time constraints.
Indicated_increase	IF TIME >= POLICY_3_START_TIME THEN POLICY_3_IDEAL_INCREASE ELSE 0	1/years	Refers to the increase of Normal pressure change rate, dependent on whether the policy has been activated or not. If the policy is not activated, there is no increase (0). If the policy has been activated, the indicated increase is equal to Policy 3 Ideal increase (0.01).
Indicated_sensitivity	IF TIME >= POLICY_2_START_TIME THEN POLICY_2_IDEAL_SENSITIVITY ELSE 1	dmnl	Refers to the sensitivity of compensating actions on stakeholder pressure, dependent on whether the policy has been activated or not. If the policy is not activated, sensitivity remains normal (1). If the policy has been activated, the sensitivity is equal to the ideal sensitivity (0.6).
INITIAL_CHANGE_IN_PRESSURE	1	Pressure/years	This variable represents the initial value of both increase and decrease of stakeholder pressure. While the results are not sensitive to this value (the equation of Relative stakeholder pressure eliminates the variables), a value of 1 is appropriate as it signifies the 'no effect' value. The variable is needed to calculate the change in both increase and decrease of stakeholder pressure.
INITIAL_RISK_OF_REMAINING_UNSUSTAINABLE	0.3	Risk	This parameter represents the initial value of the Risk of Remaining Unsustainable. The higher the value, the more favourable it is to adopt true sustainability. A high value also means that the Risk of Becoming Sustainable must decrease less in order to make firms adopt true sustainability. The initial value of 0.3 has been calibrated to achieve a behaviour similar to the reference mode and has been confirmed by J. klein Gebbinck (personal communication). A low value is appropriate, as firms are initially not in danger if they do not adopt true sustainability.
MAXIMUM_ESPR	3.3	dmnl	This value represents the maximum effect of Relative stakeholder pressure on risk. As the initial risk is 0.3, Maximum ESPR takes a value of 3.3 to make the risk reach a maximum of 1.
MAXIMUM_ETSFS	2	dmnl	This value represents the minimum effect of Truly sustainable firms on the Increase of stakeholder pressure. The value of 2 means that maximum Truly sustainable firms (1) will double the effect on the increase of stakeholder pressure (2).
MAXIMUM_RISK_OF_REMAINING_UNSUSTAINABLE	1	Risk	This value represents the maximum value Risk can take. As Risk is a ratio between 0 and 1, the maximum value is 1. The maximum risk is needed to normalize the Risk to turn it into an effect on Adoption.

MINIMUM_ESPR	0	dmnl	This value represents the minimum effect of Relative stakeholder pressure on risk. A maximum decrease (Relative stakeholder pressure = 0) can lead to a maximum decrease in risk (0).
MINIMUM_ETSFS	1	dmnl	This value represents the minimum effect of Truly sustainable firms on the Increase of stakeholder pressure. The value of 1 means that minimum Truly sustainable firms (0.05) have no effect on the increase (1).
NORMAL_PRESSURE_CHANGE_RATE	0.01+ Policy_3_implementation	1/years	This variable represents the rate at which the Increase in stakeholder pressure increases. A value of 0.01 means an increase of 0.01 in stakeholder pressure per year, which is increased slowly through the exponential function in the Exogenous growth variable. The equation also includes the effect of policy 3.
POLICY_2_IDEAL_SENSITIVITY	0.6	dmnl	Refers to the ideal value of to what extent compensating actions can influence stakeholders when the policy is into full effect. A value of 0.6 is assumed, as stakeholders will always be sensitive to compensating actions, but are able to reduce their sensitivity.
Policy_2_implementation	IF POLICY_2_SWITCH = 1 THEN Policy_2:_Critical_thinking:_sensitivity_to_compensating_actions ELSE 1	dmnl	Refers to the actual sensitivity of compensating actions on the decrease in stakeholder pressure. If the policy has not been activated, the sensitivity will be 1. Otherwise, the variable will take a value between initial sensitivity (1) and ideal sensitivity (0.6).
POLICY_2_INITIAL_SENSITIVITY	1	Dimensionless	This variable represents the initial sensitivity of stakeholders to the effect of compensating actions on their pressure, when the policy just got implemented. As there is no immediate change the moment the policy gets implemented, initial sensitivity has a value of 1.
POLICY_2_SENSITIVITY_DELAY_TIME	15	Years	This variable represents the number of years it takes for the policy to be in full effect. It is assumed that it takes 15 years before all stakeholders have adapted their perception on compensating actions, confirmed by J. klein Gebbinck (personal communication).
POLICY_2_START_TIME	2030	Years	Refers to the year in which the policy is activated. According to J. klein Gebbinck (personal communication), it takes 5 years to draw up the policy and get it approved. Starting from now, a realistic start time would thus be 2030.
POLICY_2_SWITCH	0	dmnl	This switch between 0 (inactive) and 1 (active) is used for the testing of policy 2.
Policy_2:_Critical_thinking:_sensitivity_to_compensating_actions	SMTH1(Indicated_sensitivity, POLICY_2_SENSITIVITY_DELAY_TIME, POLICY_2_INITIAL_SENSITIVITY)	dmnl	This variable represents the effect of the active policy 2. The goal of the policy is to decrease the effect of compensating actions on stakeholder pressure. It is assumed that it takes stakeholders time to adapt their perception on compensating actions. A smooth function with a delay time is therefore appropriate.
POLICY_3_EFFECTIVENESS	0.5	dmnl	This variable represents the level of effectiveness of the policy. It is assumed that the policy will not be 100% effective, as it is hard to

			activate stakeholders into exercising pressure. Therefore, an effectiveness of 50% is assumed
POLICY_3_IDEAL_INCREASE	0.01	1/years	Refers to the height of the increase of Normal pressure change rate when the policy is into full effect. A value of 0.01 is assumed, doubling the initial Normal pressure change rate.
Policy_3_implementation	Policy_3:_Awareness:_increase_in_Normal_pressure_change_rate*POLICY_3_SWITCH	1/years	Refers to the actual increase in Normal pressure change rate. If the policy has not been activated, the increase will be 0. Otherwise, the variable will take a value between initial increase (0) and ideal increase (0.01).
POLICY_3_INCREASE_DELAY_TIME	15	Years	This variable represents the number of years it takes for the policy to be in full effect. It is assumed that it takes 15 years before all stakeholders have increased their pressure due to increased awareness, confirmed by J. klein Gebbinck (personal communication).
POLICY_3_INITIAL_INCREASE	0	1/years	This variable represents the initial increase in Normal pressure change rate, when the policy just got implemented. As there is no immediate increase the moment the policy gets implemented, initial increase has a value of 0.
POLICY_3_START_TIME	2030	Years	Refers to the year in which the policy is activated. According to J. klein Gebbinck (personal communication), it takes 5 years to draw up the policy and get it approved. Starting from now, a realistic start time would thus be 2030.
POLICY_3_SWITCH	0	dmnl	This switch between 0 (inactive) and 1 (active) is used for the testing of policy 3.
Policy_3:_Awareness:_increase_in_Normal_pressure_change_rate	SMTH1(Indicated_increase, POLICY_3_INCREASE_DELAY_TIME, POLICY_3_INITIAL_INCREASE)*POLICY_3_EFFECTIVENESS	1/years	This variable represents the effect of the active policy 3. The goal of the policy is to increase the Normal pressure change rate. It is assumed that it takes stakeholders time to increase their pressure based on awareness. A smooth function with a delay time is therefore appropriate. It is also assumed that the policy might not be 100% effective, as it is hard to activate stakeholders into exercising pressure. Therefore, the effect is multiplied with the effectiveness.
Relative_risk_of_remaining_unsustainable	Risk_of_remaining_unsustainable/MAXIMUM_RISK_OF_REMAINING_UNSUSTAINABLE	dmnl	This variable represents the normalized Risk of remaining unsustainable. The normalization is necessary to turn the risk into an effect on Adoption.
Relative_stakeholder_pressure	(Absolute_increase_in_stakeholder_pressure/(Absolute_increase_in_stakeholder_pressure+Absolute_decrease_in_stakeholder_pressure))	dmnl	Relative stakeholder pressure is a ratio between 0 (maximum decrease, perceived as no pressure) and 1 (maximum increase, perceived as maximum pressure). The value is calculated by comparing the increase of stakeholder pressure to the decrease of stakeholder pressure. If the increase is greater, the variable will take a value greater than 0.5. If the increase is smaller, thus stakeholder pressure is decreasing, the value will be lower than 0.5. It is extremely hard to give a value to the absolute pressure at a certain point in time, due to not knowing where the limit is, biases,

			and bounded rationality. Therefore, the Relative increases and decreases are considered, rather than the absolute value. The variable takes an initial value of 0.5, which means that there is no change to the initial value. During the simulation, the value drops indicating a decrease, and rises to 0.5 again, representing the original value of stakeholder pressure. Later, it takes a value higher than 0.5, indicating an increase compared to the original value.
Risk_of_remaining_unsustainable	INITIAL_RISK_OF_REMAINING_UNSUSTAINABLE*"Effect_of_stakeholder_pressure_on_risk_(ESPR)"	Risk	This variable is calculated by multiplying the initial risk with the effect of stakeholder pressure. The value can both increase and decrease because of this effect. A low value means that firms are not in danger if they do not adopt true sustainability, while a high value signifies high danger.
STEEPNESS_ESPR	12.2	dmnl	This variable represents the steepness of the slope of the S-shape. The slope is rather high, indicating a slow increase with a low value of Relative stakeholder pressure, followed by a steep increase, finishing with a slow increase again as Relative stakeholder pressure takes a high value.
STEEPNESS_ETSFS	10	dmnl	The steepness is calibrated to the normal slope of an S-shaped graphical function.
X_FINISH_ESPR	1	dmnl	The value of 1 represents the maximum value that Relative stakeholder pressure can take, as it is a ratio.
X_FINISH_ETSFS	1	dmnl	The value of 1 represents the maximum value that Relative truly sustainable firms can take, as it is a ratio.
X_MIDDLE_ESPR	0.565	dmnl	The middle of the S-shaped curve is calibrated in such a way that initial stakeholder pressure (0.5) has no effect (1) on the risk. Accordingly, an increase of Relative stakeholder pressure (>0.5) has an increasing effect on the risk, while a decrease (<0.5) has a decreasing effect.
X_MIDDLE_ETSFS	0.525	dmnl	This value represents the middle of the S-shaped curve. As the curve is symmetrical and ranges between 0.05 and 1 on the x-axis, a value of 0.525 is appropriate.
X_START_ESPR	0	dmnl	The value of 0 represents the minimum value that Relative stakeholder pressure can take, as it is a ratio.
X_START_ETSFS	0.05	dmnl	The value of 0.05 represents the minimum value that Relative truly sustainable firms can take, as it is a ratio, and the initial value of Truly sustainable firms is 5 (out of 100).
Resistance			
Change_resistance_influenced_by_stakeholder_pressure	INITIAL_CHANGE_RESISTANCE*(1-Relative_stakeholder_pressure)	Resistance	This variable represents the Change resistance taking into consideration stakeholder pressure. The higher the pressure, the lower the resistance to Adoption. Pressure rising means that firms are not able to regulate the pressure with compensating actions. Therefore, they realize that they must implement true sustainability, thus decreasing their resistance. It is assumed that there is a linear negative effect between stakeholder pressure and change resistance. Therefore, the effect of stakeholder pressure on

			change resistance is represented by the formulation (1-Relative stakeholder pressure). This is then multiplied by the Initial change resistance.
Change_resistance_to_adoption	Change_resistance_influenced_by_stakeholder_pressure/INITIAL_CHANGE_RESISTANCE	dmnl	This variable represents the normalized Change resistance. The normalization is necessary to turn the resistance into an effect on Compensating actions and the Adoption of true sustainability.
INITIAL_CHANGE_RESISTANCE	1	Resistance	This variable represents the initial value of change resistance. A value of 1 is assumed, as firms are very resistant to true sustainability, as implementing compensating actions is much easier. The resistance is then immediately adjusted to the existing stakeholder pressure in the variable 'Change resistance influenced by stakeholder pressure', making the value more realistic.

Run Specs	
Start Time	1940
Stop Time	2100
DT	1/32
Fractional DT	True
Save Interval	Every DT
Sim Duration	1.5
Time Units	Years
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	True
Exhaustive Search Threshold	1000

Custom Unit	Aliases	Equation
Dimensionless	dmnl unitless	1
kilowatt hours per day		kWh/day
kilowatts	kilowatt	kW

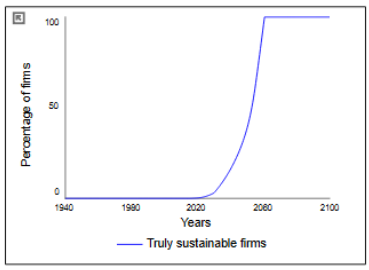
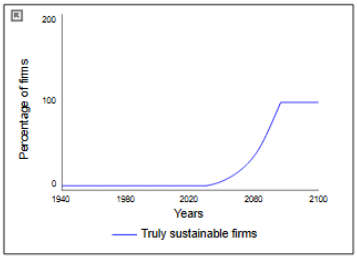
Appendix C: Model validation

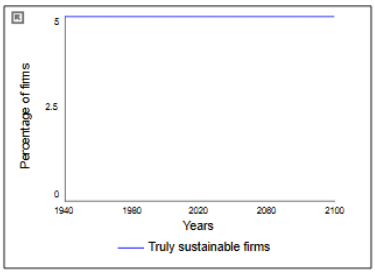
To build confidence in the model and the simulation results, the model validation tests documented by Barlas (1996) have been conducted:

Structure confirmation test: The model structure was constructed to match the reference mode, based on literature and consultation with the teaching assistant of the University of Bergen, and confirmed by J. klein Gebbinck (personal communication, 11 December 2024). Equations were evaluated against alternatives and determined to be the most suitable for reproducing the reference mode. The structure was considered a realistic representation of adoption of true sustainability for SMEs in the industrial sector.

Parameter confirmation test: All parameters hold real world meaning. As the model structure consists of mostly soft variables, many variables have been given a value within a ratio between 0 and 1. This documentation makes sure that most variables have a relative meaning, true to real world meaning. The specific value of initials and delay times has been derived from logic or literature, and confirmed or adjusted by J. klein Gebbinck (personal communication), see Appendix B. All uncertain parameters have undergone sensitivity testing, which can be found in further in the appendix.

Extreme condition test: Extreme conditions tests produced behaviours that aligned with realistic expectations in a real-life context. Some equations have been adjusted accordingly using MIN and MAX functions. Impossible values have not been tested, such as a negative stock of Unsustainable firms, Relative stakeholder pressure above its maximum value of 1, or Uncertainty with a negative value. The table below shows three examples of the extreme conditions test. Other extreme condition tests resulted in similar conclusions.

Extreme condition	Effect on Truly sustainable firms	Conclusions
0 initial Truly sustainable firms and 100 Unsustainable firms		Passed. The effect of truly sustainable firms on stakeholder pressure and uncertainty is able to convert a stock of 0 into an effect.
100 initial Uncertainty		Passed. Even though an initial value of 100 is impossible, as uncertainty is a ratio between 0 and 1, a value of 100 expectedly slows down R1, and thus adoption of true sustainability.

100 initial risk of becoming sustainable		Passed. The initial risk is so high that the risk of remaining unsustainable will never surpass it, thus leaving adoption at 0 and Truly sustainable firms at its initial value of 5.

Integration test: The results from the base scenario were produced using a DT of 1/32. While the smallest time variable is 1/100, and according to the rule of thumb DT should be minimally twice as small, a minimal DT of 1/32 is appropriate. The model is sensitive to a bigger DT and not sensitive to a smaller DT. The integration method of Euler has been chosen as most appropriate, as the model is not sensitive to an alternative integration method (RK4), and Euler is the least computationally intensive.

Dimensional consistency test: The Stella software verified that this model maintains dimensional consistency and is free of unit errors.

Behaviour sensitivity test: The parameters were checked for behavioural inconsistencies, with detailed analysis provided further in the appendix.

Behaviour pattern reproduction: The reference modes have been met.

Partial model (sector) testing: Each sector was tested individually with constant inputs, confirming structural soundness and appropriate behaviour in isolation.

Assumptions

Next to the model validation tests, it is important to highlight the assumptions and model boundaries made while building the model:

- All firms are aware of the existence of SBMs, but not of their most successful implementation. Future research could include the 'Word-of-mouth' loop from the Bass diffusion model to make this model more accurate.
- Knowledge on SBMs is based on firms that have successfully implemented SBMs. The model indirectly assumes the effect of Truly sustainable firms on the amount of research on SBMS, both academic and practical (also by firms that have not implemented SBMs yet). However, the linearity of the effect is unknown and could be modelled more explicitly.
- Knowledge on SBMs is not subject to any type of knowledge risks, such as knowledge loss (Durst & Wilhelm, 2011), knowledge outsourcing (Williams & Durst, 2018), knowledge leakage (Parker, 2012), knowledge hiding (Arshad & Ismail, 2018), knowledge hoarding (Holten et al., 2016), and knowledge spillover (Feinberg & Gupta, 2004). Future models could include the direct mediating effect of knowledge, comprising the decrease of knowledge due to the risks mentioned above.

- All firms have equal access to knowledge on SBMs. Specific characteristics of firms like knowledge management (Durst & Zieba, 2019) that influence the ability of processing knowledge and thus decrease uncertainty fall outside of the model boundaries.
- Specific events that increased stakeholder pressure at certain moments, such as the climate summits and big climate disasters have not been considered. The smoothed effect of these events has been incorporated into the model through the variable exogenous growth but could be modelled more explicitly according to the findings of Baiardi and Morana (2020).
- Firms are mostly driven by stakeholder pressure and uncertainty. This paper left out stakeholders that pressure firms not to become sustainable, often represented by shareholders. The countereffect of this type of stakeholder could present interesting structure and results.

Local Sensitivity Analysis

The model contains uncertain parameters for which the value has been assumed either from literature, the interview, or logic. All uncertain parameters have been tested using Local Sensitivity Analysis on the base scenario. The analysis is conducted using Stella's Sensitivity Analysis tool, using Sobol Sequence Sampling for reproducibility. The analysis uses 50 runs for accurate results, and uniform distribution as the distribution is unknown. The table below shows each sensitive parameter with its uncertainty range that has been used in the test, and the type of sensitivity. Below the table each uncertain parameter is analysed for its sensitivity on the KPIs Truly sustainable firms, Perceived uncertainty, and Relative stakeholder pressure. Partly based on this analysis, the parameters with the most (realistic) leverage have been selected for policymaking.

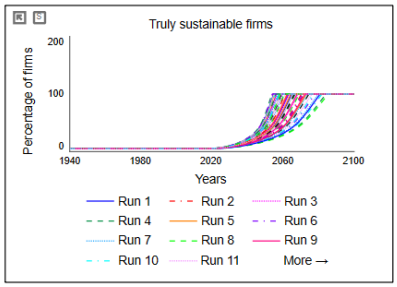
As expected, parameters with absolute values (delay times, initial values, maximum effect) were the most uncertain. Therefore, the model cannot produce accurate numerical estimations such as the exact moment in time where 100% of firms achieve true sustainability. Nevertheless, the model structure provides behaviour insights appropriate for the model purpose. Exact data points are not the primary focus. Instead, the emphasis is on behavioural patterns that align closely with the model's expected outcomes.

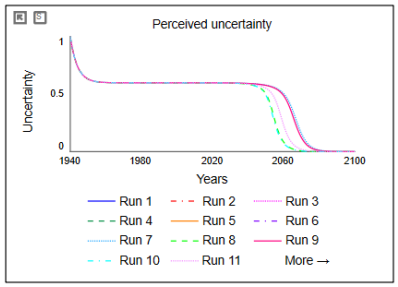
Model sector	Parameter	Range	Sensitivity
Adoption	Ideal adoption	5-15	Numerical
Compensating actions	Actions implementation delay time	1-10	Behavioural
	Normal compensating actions	1-5	Behavioural
	Threshold compensating actions	12.5-37.5	Behavioural
	Y to 5	2-6	Behavioural
Knowledge and uncertainty	Initial risk of becoming sustainable	0.2-0.8	Numerical
	Initial uncertainty	0.3-0.9	Behavioural
	Uncertainty perception delay time	2-6	Numerical
Pressure	Initial risk of remaining unsustainable	0.1-0.5	Numerical
	Normal pressure change rate	0-0.1	Behavioural
	Y to 4	1-3	Numerical

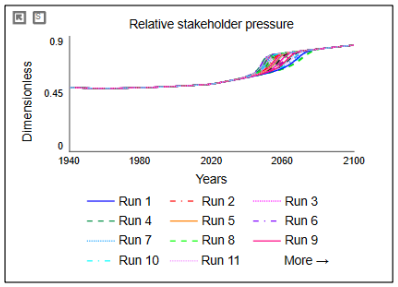
Table 1 Overview of uncertain and sensitive parameters

Adoption

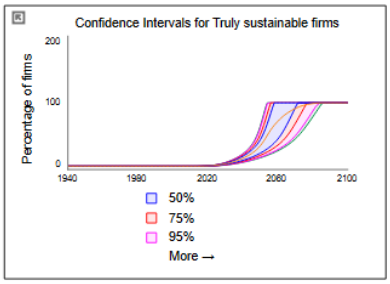
Ideal adoption [5-15 years]

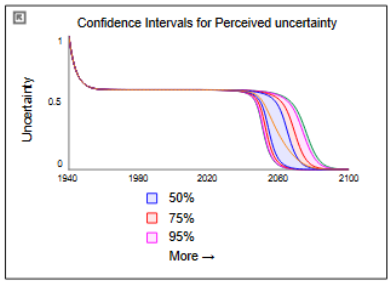


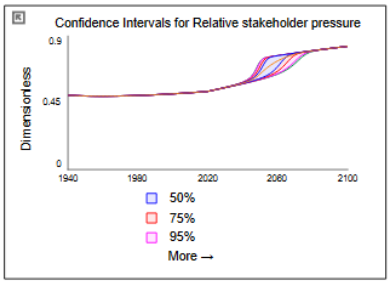




The KPIs are numerically sensitive to Ideal Adoption. Especially the stock Truly sustainable firms is sensitive, since Ideal adoption affects its flow directly. Ideal adoption represents the percentage of firms that would adopt true sustainability per year under perfect conditions. The higher its value, the faster the growth of Truly sustainable firms. Since both Perceived uncertainty and Relative stakeholder pressure are indirectly affected by Truly sustainable firms, a faster growth in the latter means a faster growth in the two KPIs.



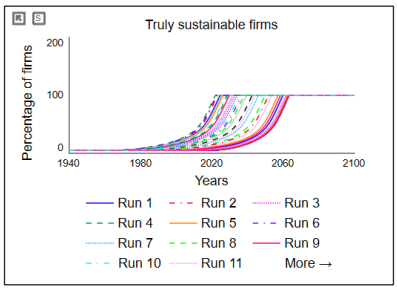


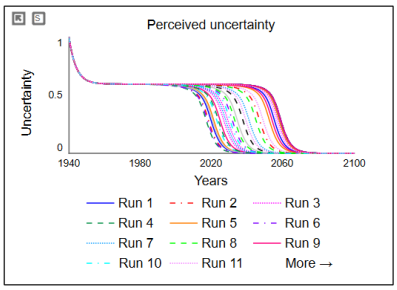


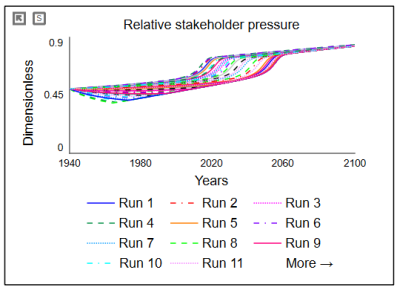
CI 95%: [100-100] [0-0] [0.832-0.832]

Compensating actions

Action implementation delay time [1-10 years]





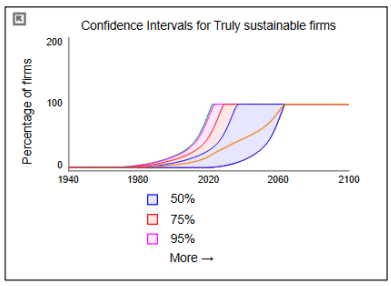


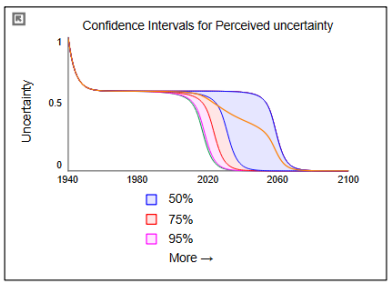
Truly sustainable firms and Perceived uncertainty are both numerically sensitive to Action implementation delay time, while Relative stakeholder pressure is behavioural sensitive to the variable.

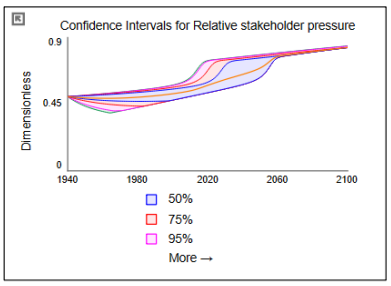
Perceived uncertainty is affected by Relative stakeholder pressure through Truly sustainable firms. The higher the delay time, the sooner Relative stakeholder pressure will increase. Thus, the sooner the risk of remaining unsustainable will be higher than the risk of becoming sustainable, and firms start adopting. This development then increases Truly sustainable firms and Perceived uncertainty. Therefore, the higher the delay time, the faster Truly sustainable firms reach 100, and the faster Perceived uncertainty drops.

The relationship between the delay time and Relative stakeholder pressure is however not so straightforward. Values higher than 4 create an S-shaped increase, while values lower than 4 make Relative stakeholder pressure drop before increasing to the same level. As the delay time is shorter, more compensating actions can be implemented in the same amount of time. The Decrease in stakeholder pressure is now able to grow bigger than the increase, creating an initial decrease in Relative stakeholder pressure. As stakeholder pressure starts to increase gradually because of the exogenous growth, and decrease in stakeholder pressure is limited to 2, Relative stakeholder pressure will start increasing again.

For values of delay time above 4, firms are not implementing the compensating actions fast. Decrease in stakeholder pressure therefore grows slower. Meanwhile, the exogenous growth has increased the Increase in stakeholder pressure enough for it to be higher than Decrease in stakeholder pressure. Because of this, the behaviour is S-shaped and does not include the initial dip.

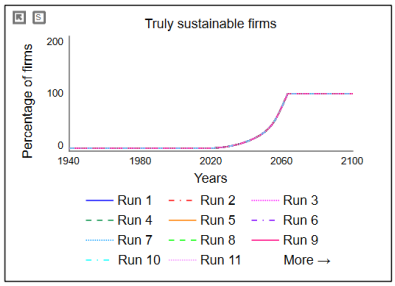


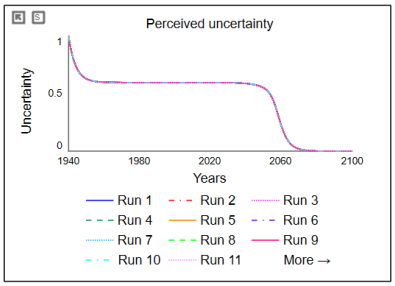


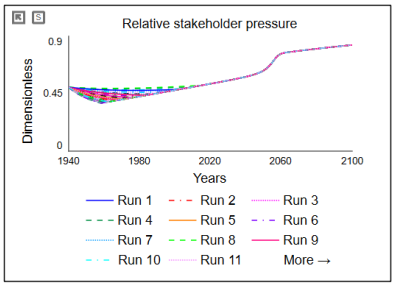


CI 95%: [100-100] [0-0] [0.832-0.842]

Normal compensating actions [1-5 actions]

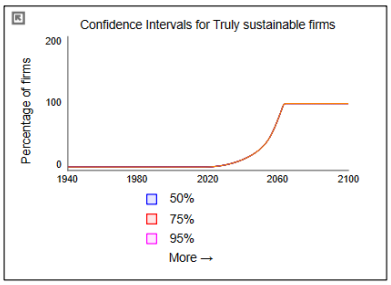


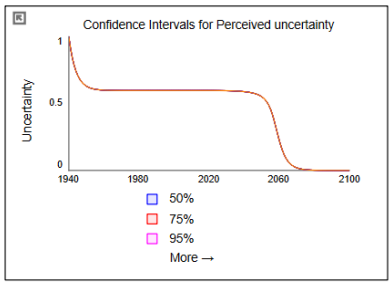


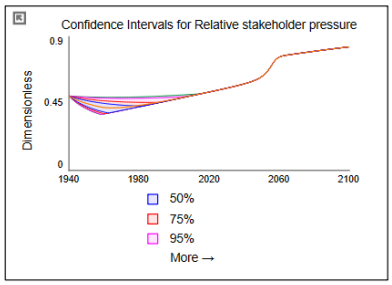


Truly sustainable firms and Perceived uncertainty are not sensitive to Normal compensating actions. Relative stakeholder pressure is behaviourally sensitive to the variable for all values above 1. The higher the Normal compensating actions, the faster the Decrease in stakeholder pressure grows. The growth is bigger than the Increase in stakeholder pressure, leading to a decrease in Relative stakeholder pressure, similar to the effect of a lower Action implementation delay time as explained above. As the Increase in stakeholder pressure grows exogenously over time, it will overpower the decrease, leading to an increase in Relative stakeholder pressure.

At the moment that Relative stakeholder pressure starts increasing again, the Risk of becoming sustainable is still higher than the Risk of remaining unsustainable, which is why you see no change in the other two KPIs.

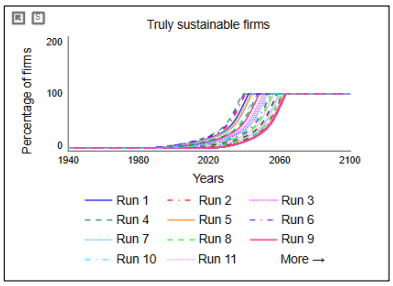


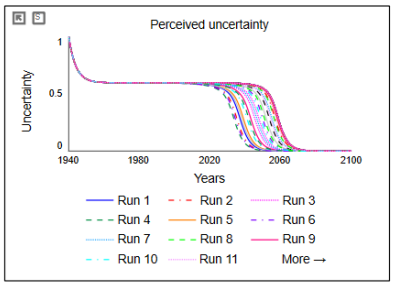


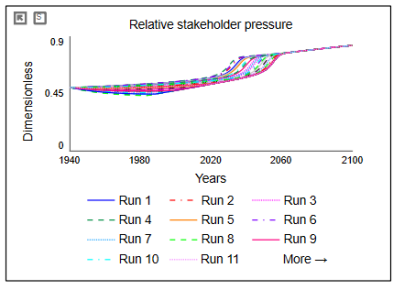


CI 95%: [100-100] [0-0] [0.832-0.832]

Threshold compensating actions [12.5-37.5 actions]

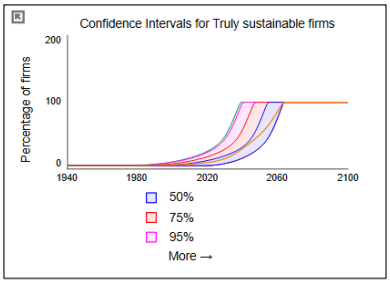


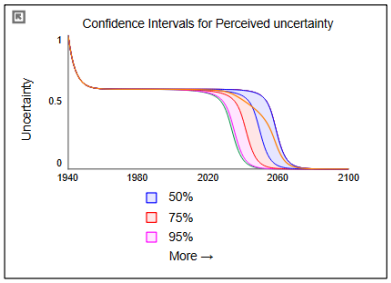


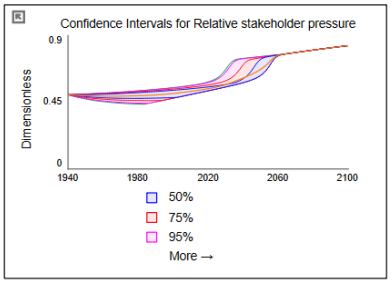


Similar to some of the variables described above, Truly sustainable firms and Perceived uncertainty are numerically sensitive to Threshold compensating actions. The lower the Threshold, the sooner the Decrease effect will come to a halt and the Increase in stakeholder pressure will overtake the decrease. The increase in Relative stakeholder pressure leads to an increase in Risk of remaining unsustainable. This leads to an increase in adoption of Truly sustainable firms, and consequently an increase in Perceived uncertainty.

Relative stakeholder pressure is behaviourally sensitive to the Threshold of compensating actions for the same reasons as it is behaviourally sensitive to the variables discussed before. A decrease in the threshold below 27.5 makes that Relative compensating actions reaches the value of 1 sooner, which means that the Decrease in stakeholder pressure grows faster than the Increase in stakeholder pressure, which creates the dip. After a certain time, Increase in stakeholder pressure increases exogenously, leading to an increase in Relative stakeholder pressure shown in the graph. With a threshold higher than 27.5, the Decrease doesn't grow faster than the Increase, avoiding the dip.

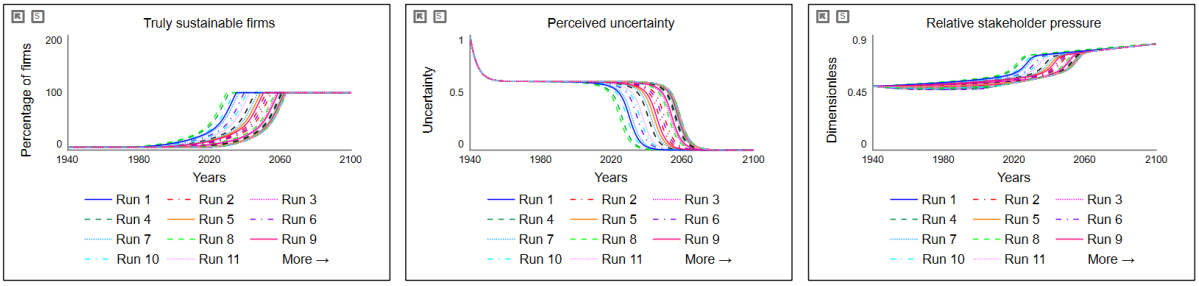






CI 95%: [100-100] [0-0] [0.832-0.832]

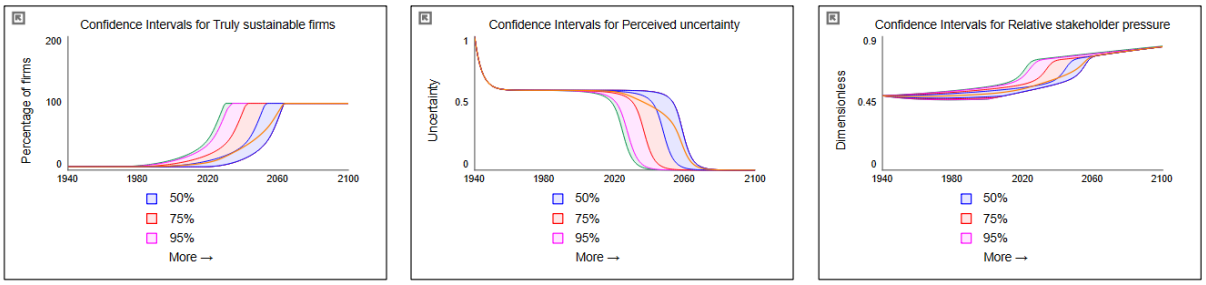
Maximum effect of pressure on compensating actions [2-6 dimenionless]



Relative stakeholder pressure is behaviourally sensitive to the range. For values above 4, Relative stakeholder pressure will show a dip before the S-shaped increase. As a higher value means a greater positive effect on the Indicated compensating actions, more actions will be implemented, reaching a Relative compensating actions value of 1 sooner in the simulation time. This makes that the Decrease in stakeholder pressure initially grows faster than the Increase in stakeholder pressure, causing the dip. After the Effect of compensating actions on Decrease in stakeholder pressure comes to a halt and Increase in stakeholder pressure keeps growing (exogenously), Relative stakeholder pressure starts growing again. This development delays the Adoption of true sustainability, as the Risk of remaining unsustainable increases at a later point in time. This makes that the Risk of remaining unsustainable will overtake the Risk of becoming sustainable at a later point as well, leading to a later Adoption of true sustainability. This leads to a later increase in Truly sustainable firms, and consequently Perceived uncertainty, making both KPIs numerically sensitive to the maximum effect.

While a change in the Maximum effect leads to a shift in the starting time of increase in Truly sustainable firms, and a decrease in Perceived uncertainty, it does not change the speed at which it happens. This is because the B1 loop only affects the moment when Risk of remaining unsustainable overtakes the Risk of becoming sustainable. It does not change the speed, as the Effect of compensating actions on stakeholder pressure halts after a Relative compensating actions of 1, shifting the loop dominance away from B1.

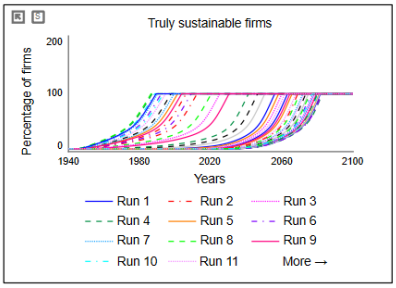
For values below 4, Relative compensating actions will reach a value of 1 in a later point in time. The Increase in stakeholder pressure will have grown more than the Decrease in stakeholder pressure, leading to an increase in Relative stakeholder pressure and avoiding the dip. This means that Relative stakeholder pressure starts to grow sooner, leading to a sooner growth in Risk of remaining unsustainable. Because of this growth, Risk of remaining unsustainable will overtake Risk of becoming sustainable sooner, leading to the start of Adoption of true sustainability to be moved forward. Therefore, Truly sustainable firms grow earlier, and consequently Perceived uncertainty, showing numerical sensitivity to the Maximum effect again.

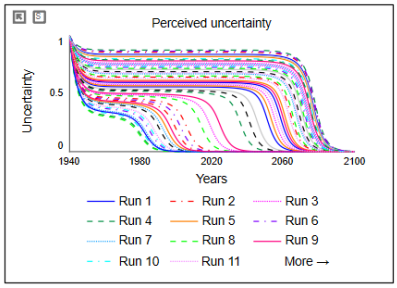


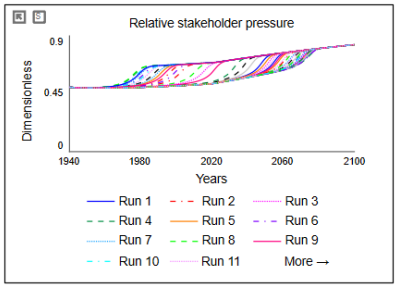
CI 95%: [100-100]	[0-0]	[0.832-0.833]

Knowledge and uncertainty

Initial uncertainty [0.3-0.9 uncertainty]

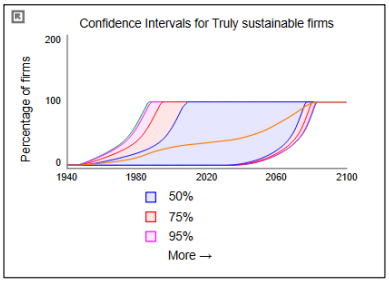


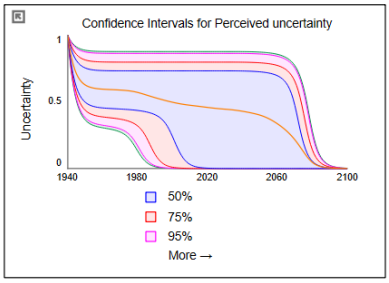


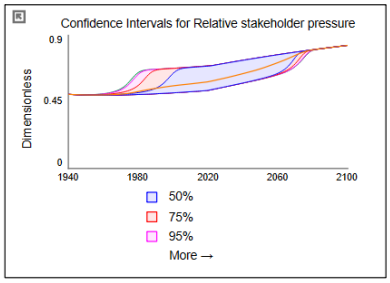


Truly sustainable firms and Relative stakeholder pressure are numerically sensitive to Initial uncertainty. The higher the uncertainty, the later the Risk of remaining unsustainable will overgrow the Risk of becoming sustainable, delaying the adoption of true sustainability. As adoption starts later, Truly sustainable firms will reach the ideal 100% later. Relative stakeholder pressure is dependent on Truly sustainable firms. Thus, the later Truly sustainable firms grows, the later Relative stakeholder pressure grows.

Perceived uncertainty is behaviourally sensitive to Initial uncertainty. For values above 0.55, Perceived uncertainty reaches a constant value for an extended period before decreasing again. A high Initial uncertainty means that the Risk of becoming sustainable is also rather high, which delays the overtake of Risk of remaining unsustainable on the Risk of becoming sustainable, thus delaying the Adoption of true sustainability. As Truly sustainable firms will increase at a later point in time, the stock will have no decreasing effect on uncertainty until that point in time, creating the constant behaviour of Perceived uncertainty. With a lower value than 0.55, however, Risk of becoming sustainable is overtaken by the Risk of remaining unsustainable sooner, which means that Truly sustainable firms starts growing earlier, leading to Perceived uncertainty continuously decreasing (at different rates).

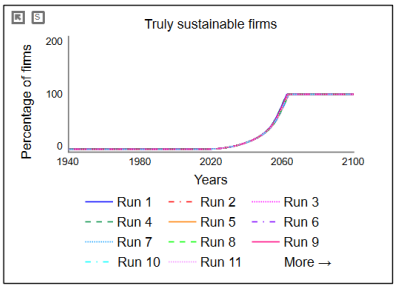


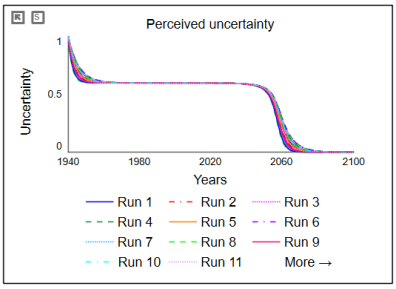


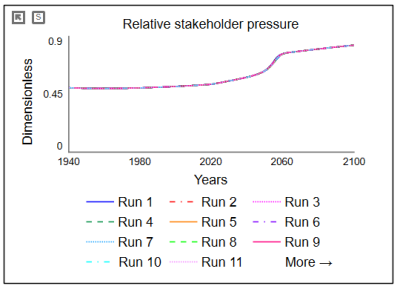


CI 95%: [100-100] [0-0] [0.832-0.833]

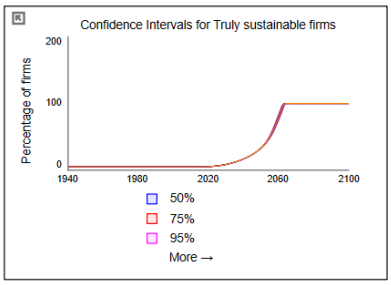
Uncertainty perception time [2-6 years]

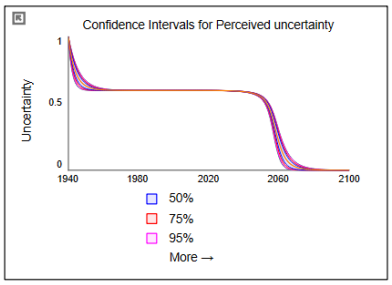


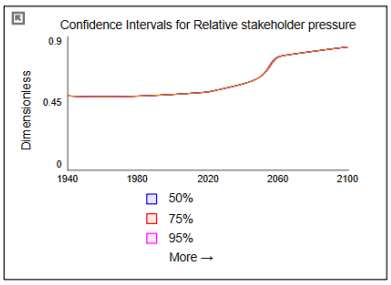




Truly sustainable firms and Relative stakeholder pressure are incredibly slightly sensitive to Uncertainty perception time (around t = 2060). Perceived uncertainty is a bit more numerically sensitive to the perception time. This makes sense, as Perceived uncertainty is directly affected by the perception time. The longer the perception time, the smoother the curve. The smoothing at the beginning of the simulation time has no effect on the other two KPIs, as the R1 and R2 loops haven't come into effect yet. The second smoothing, however, slightly changes the numerical behaviour of the two KPIs. A longer perception time leads to a later adjustment of Perceived perception, thus a later increase in Truly sustainable firms, and therefore a later increase in Relative stakeholder pressure.

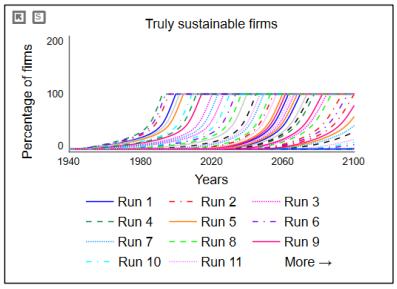


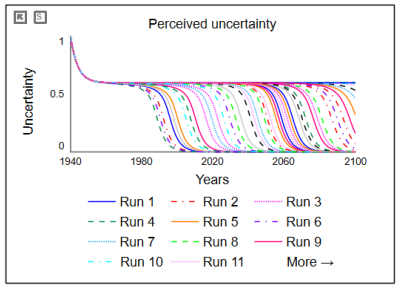


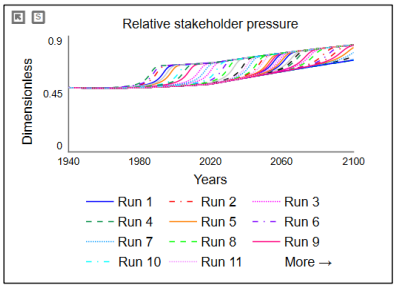


CI 95%: [100-100] [0-0] [0.832-0.833]

Initial risk of becoming sustainable [0.2-0.8 risk]

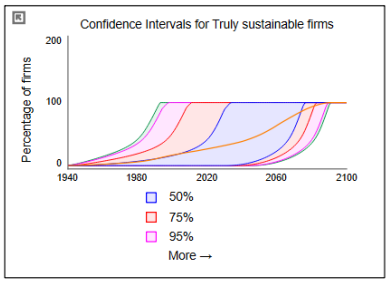


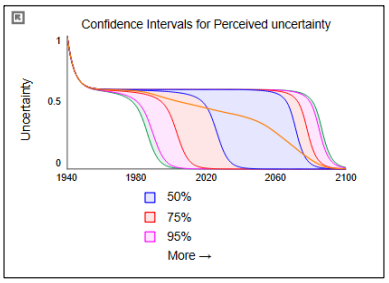


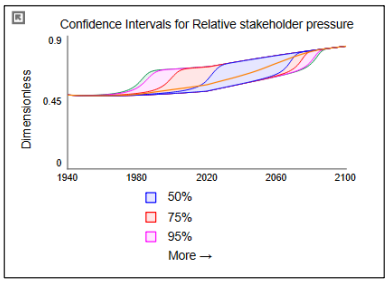


All three KPIs are numerically sensitive to the Initial risk of becoming sustainable. The higher the Initial risk, the later in time the Risk of remaining unsustainable will take over, delaying the Adoption of true sustainability. Because of this delay, Truly sustainable firms will start to grow later, and therefore Perceived uncertainty and Relative stakeholder pressure will increase later. A lower value of Initial risk of becoming sustainable has the opposite effect.

However, while the variable is theoretically good for policymaking, in practice it would not make sense. The value is fixed, and the goal of the model is to endogenously decrease the value so that Adoption of true sustainability can increase.



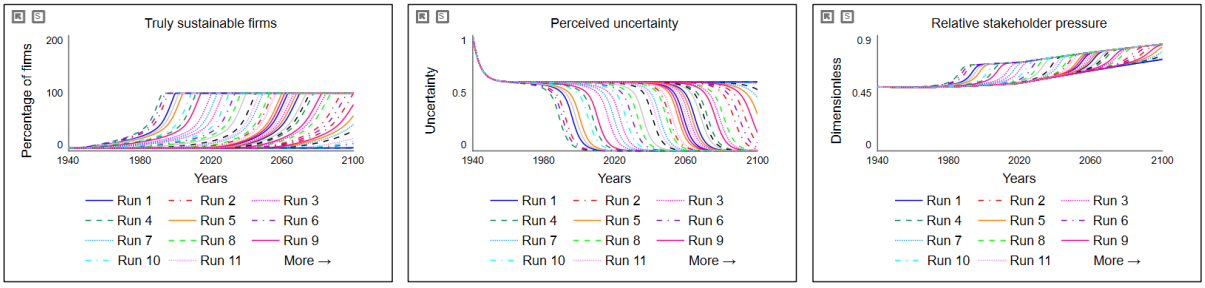




CI 95%: [100-100] [3.19e-13-0.00719] [0.832-0.833]

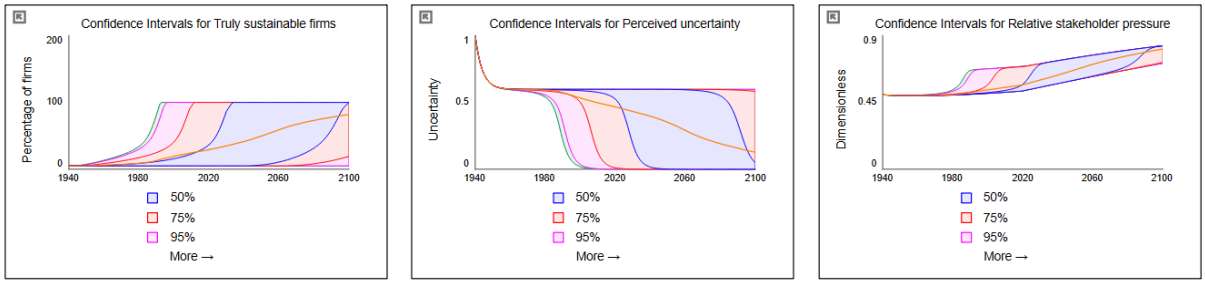
Pressure

Initial risk of remaining unsustainable [0.1-0.5 risk]



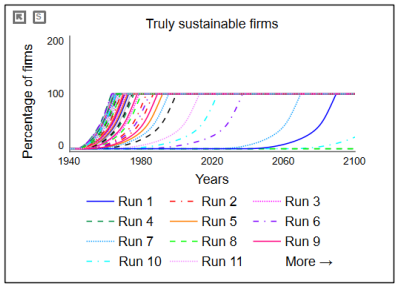
Initial risk of remaining unsustainable has a similar effect to the KPIs as Initial risk of becoming sustainable. In this case, the higher the risk, the earlier the Adoption will start, activating R1 and R2. Because of the earlier activation of these loops, Perceived uncertainty and Relative stakeholder pressure will also change earlier. For Perceived uncertainty this means that it will decrease earlier and faster. For Relative stakeholder pressure this means that it will increase earlier and faster.

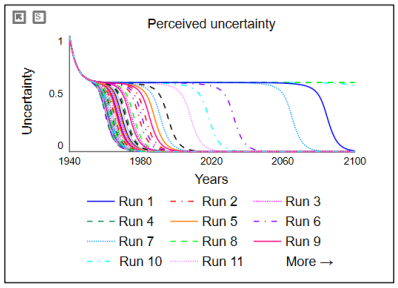
Similarly to the Initial risk of becoming sustainable, this value is fixed, making it inappropriate for policymaking.

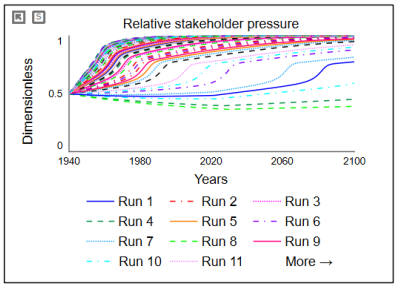


CI 95%: [5-100] [4.53e-13-0.598] [0.713-0.832]

Normal pressure change rate [0-0.1 1/years]

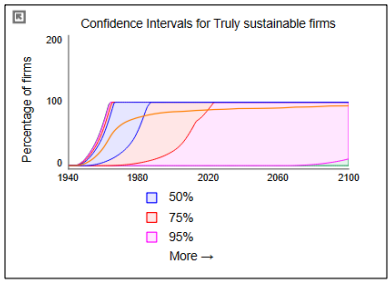


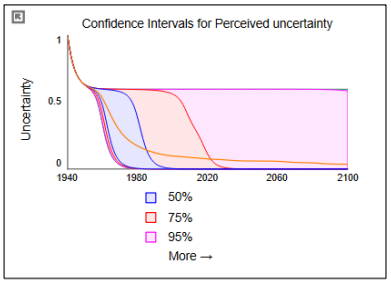


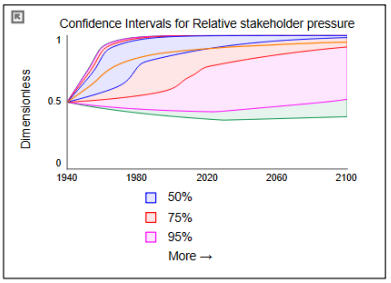


Truly sustainable firms and Perceived uncertainty are numerically sensitive to Normal pressure change rate. As the rate increases, Relative stakeholder pressure increases, thus increasing the Risk of remaining unsustainable. The higher the risk, the sooner the Adoption of true sustainability will start to increase. Because of this effect, Truly sustainable firms will increase earlier and faster, and consequently Perceived uncertainty decreases faster. Note that run 4 (the green striped line) may seem to be in equilibrium for Truly sustainable firms and reach an equilibrium in Perceived uncertainty. However, the run creates the same behaviour as the other runs over a longer time period, which continues beyond the simulation time.

Relative stakeholder pressure is behaviourally very sensitive to Normal pressure change rate. For values higher than 0.01, the change rate creates an increased Increase in stakeholder pressure. The higher the value, the bigger the growth of Increase in stakeholder pressure, and consequently Relative stakeholder pressure. For values lower than 0.01, the Increase in stakeholder pressure initially does not grow faster than Decrease in stakeholder pressure, creating a dip in Relative stakeholder pressure. The lower the value, the longer it takes Relative stakeholder pressure to reach its initial value again.

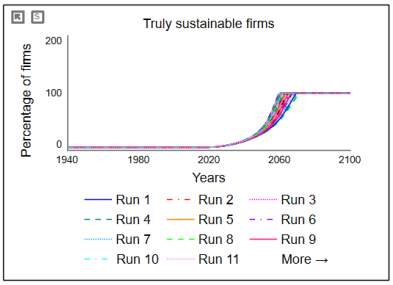


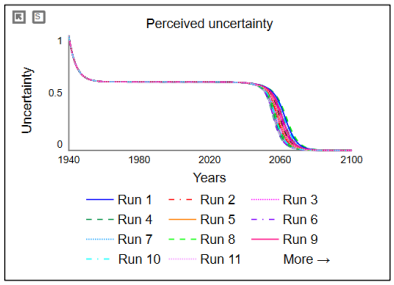


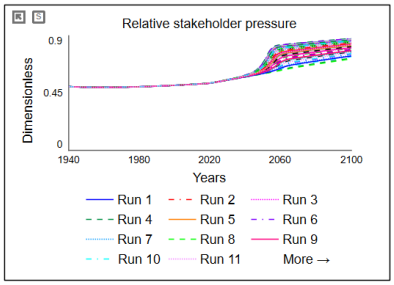


CI 95%: [15.1-100] [2.02e-16-0.585] [0.523-0.832]

Maximum effect of truly sustainable firms on stakeholder pressure [1-3 dimensionless]

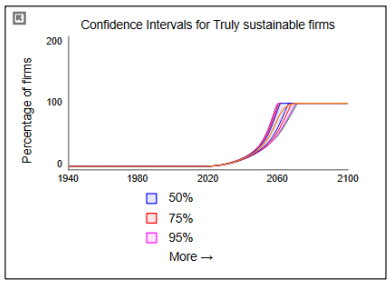


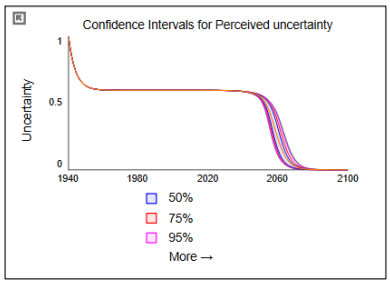


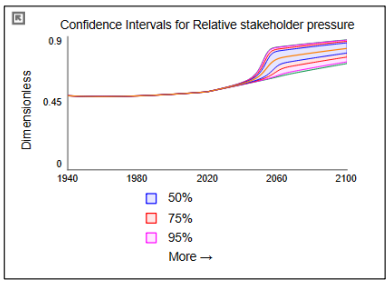


All KPIs are slightly numerically sensitive to the extent of the range of the Effect of truly sustainable firms on stakeholder pressure. The greater the effect, the more Relative stakeholder pressure grows. An increase in Relative stakeholder pressure leads to an increase in the Risk of remaining unsustainable. The higher the risk, the faster adoption grows and therefore Truly sustainable firms, and consequently Perceived uncertainty. As the Effect of truly sustainable firms on stakeholder pressure only grows when Truly sustainable firms grows, the effect will only lead to a steeper slope of the KPIs, not an earlier effect.

Note that the runs of Relative stakeholder pressure that seem to present exponential growth are actually showing an S-shaped growth with a very gradual slope.







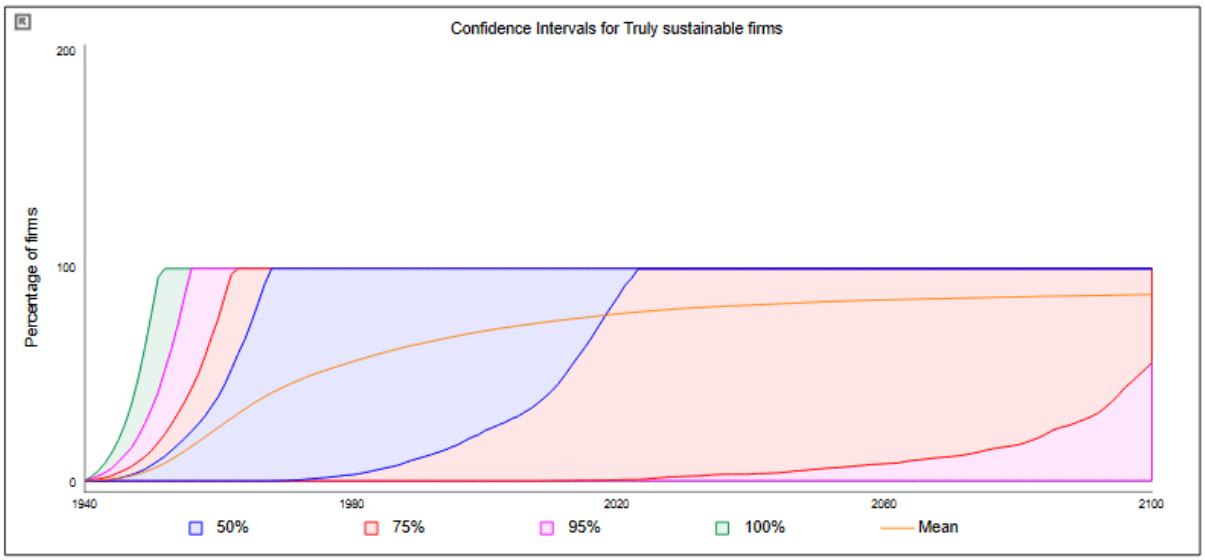
CI 95%: [100-100] [0-0] [0.73-0.877]

Global Sensitivity Analysis

The model contains uncertainty due to the assumed parameters visualised in table 1. These parameters have been locally tested in the Local Sensitivity Analysis. While the local analysis shows the uncertainty per parameter, it does not allow to see the uncertainty that occurs when uncertain parameters interact with each other. Therefore, a Global Sensitivity Analysis was conducted, indicating the uncertainty of different parameter value combinations. The output of the analysis show the 95% confidence intervals of the KPIs (Truly sustainable firms, Perceived uncertainty, and Relative stakeholder pressure) from 1000 runs based on the Sobol Sequence Sampling method. The output is sensitive to less than 1000 runs, but not to more than 1000 runs, making a total of 1000 appropriate for the multivariate analysis. The analysis shows the behaviour constructed by the full range of possibilities for the KPIs, indicating the different effects the combinations of parameter values have on the KPIs.

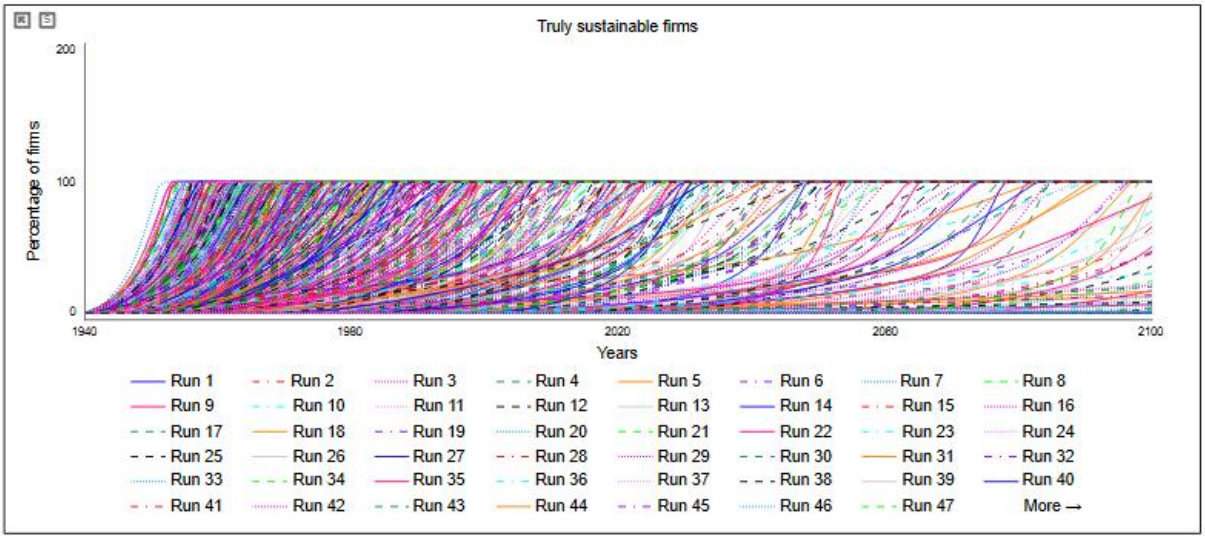
Truly sustainable firms

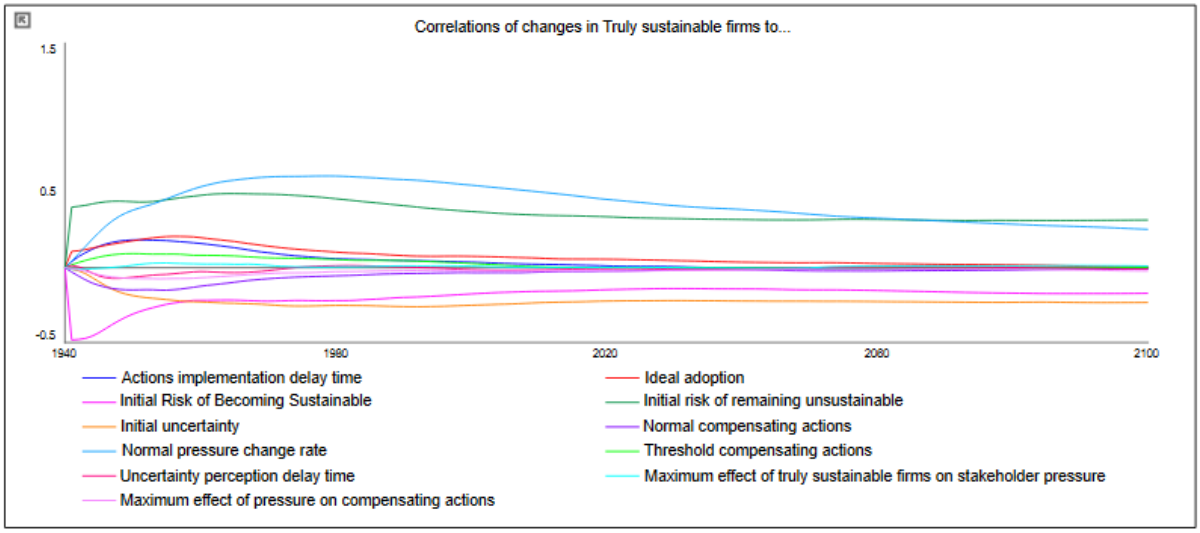
The model produces a range of Truly sustainable firms from 5% to 100% by 2100, see the figure below. It is not surprising that the confidence interval is so great, as the Local Sensitivity Analysis showed that the model is very sensitive to its uncertain parameters.



The figure shows two different behavioural patterns: 1) S-shaped increase, and 2) equilibrium. The form of the s-shaped increase is determined by both the speed at which the KPI increases, and the moment in which it starts increasing. The speed by which the KPI grows is dependent on the parameters within the R1 and R2 loops. The stronger the loops, the faster Truly sustainable firms will achieve 100%. The moment in which the KPI starts to grow is dependent on the activation of the variable Effect of risk and resistance on adoption. The variable is activated when the Risk of remaining unsustainable is greater than the Risk of becoming sustainable. This point in time is mainly dictated by the dominance shift from B1 and R3 to R1 and R2. Parameters within B1 and R3 are therefore responsible for determining the moment in which Truly sustainable firms starts to grow. If the dominance shift never occurs, Truly sustainable firms will achieve an equilibrium at its initial value.

The figure below shows all the possibilities of behaviour of Truly sustainable firms. The figure clearly shows behaviour that differs in speed and start time of the increase, including the equilibrium at 5% Truly sustainable firms.





Truly sustainable firms is initially most affected by the two risks: Initial risk of becoming sustainable has the most effect on the KPI with a correlation value of -0.483, followed by Initial risk of remaining unsustainable with a correlation value of 0.41. During this initial phase, Adoption of true sustainability is not yet activated, as the Risk of remaining unsustainable is lower than the Risk of becoming sustainable. This activates mainly the B1 and R3 loops, keeping Relative stakeholder pressure low and preventing Adoption to be activated.

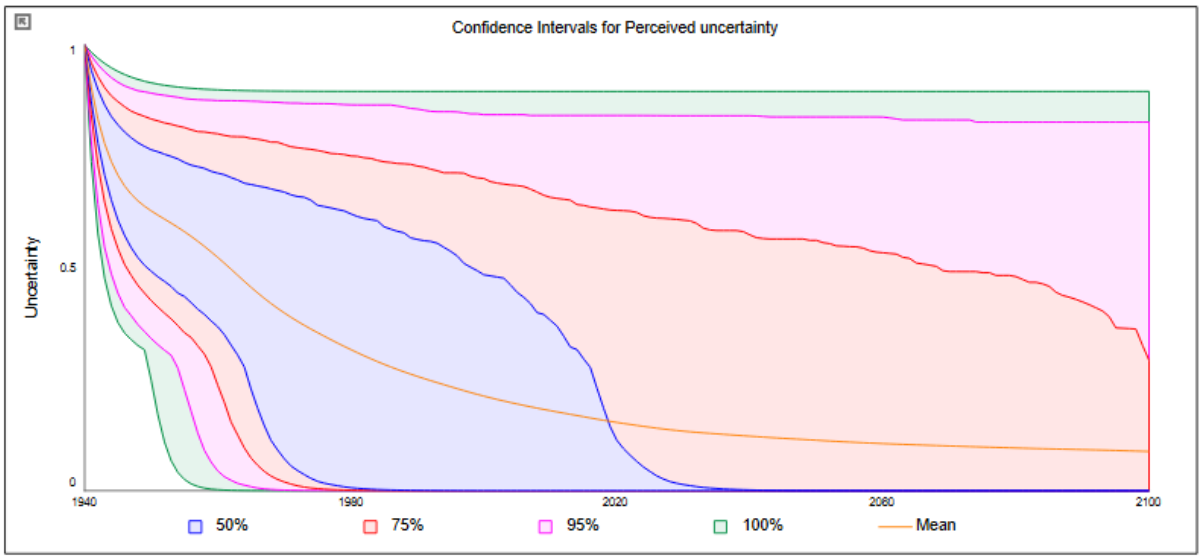
The figure shows that Normal pressure change rate starts affecting the KPI increasingly during the initial phase. Around 1955, the variable achieves a greater effect on the KPI than the two risks, with a maximum impact of 0.613 occurring right before time 1880. This is explained by the Normal pressure change rate increasing the Increase in stakeholder pressure enough to overpower the Decrease in stakeholder pressure, leading to a growth in Relative stakeholder pressure, and therefore Risk of remaining unsustainable. The figure shows that the correlation of the Risk of remaining unsustainable remains rather constant as it is driven by the Relative stakeholder pressure, while the correlation of the Risk of becoming sustainable decreases. During this period, the loop dominance has shifted from B1 and R3 to R1 and R2.

Around this time the correlation of Initial uncertainty increases as well, reaching a maximum impact of -0.261 around 1990. As the loop dominance has partially shifted to R1, Truly sustainable firms has started to affect Perceived uncertainty, which is influenced by Initial uncertainty.

It makes sense that the four most important parameters affecting Truly sustainable firms are the Risk of remaining unsustainable, which is greatly affected by Relative stakeholder pressure and thus Normal pressure change rate, and the Risk of becoming sustainable, which is greatly affected by Perceived uncertainty and thus Initial uncertainty.

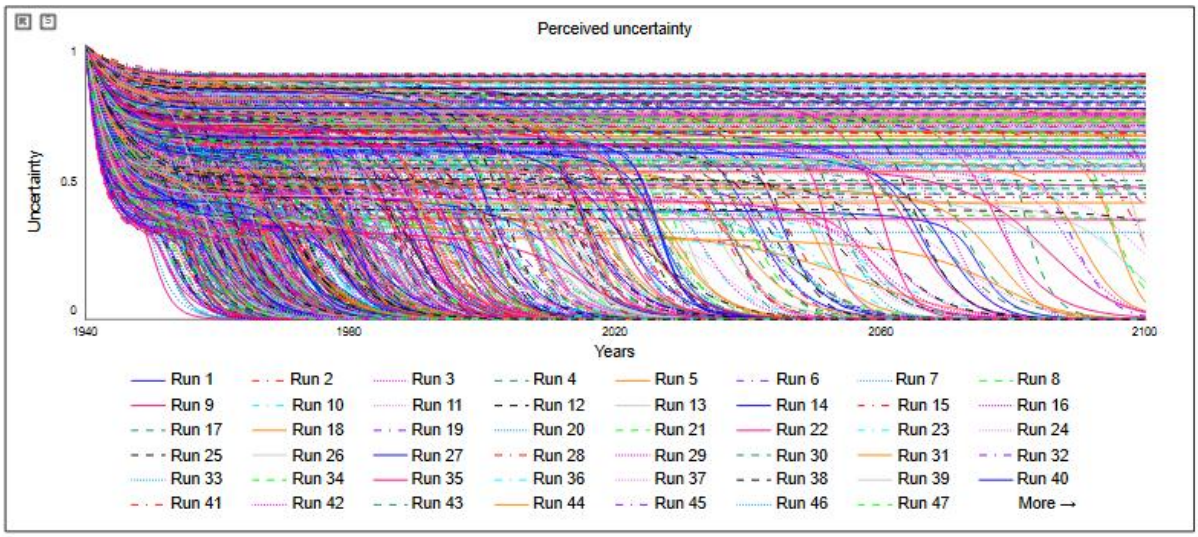
Perceived uncertainty

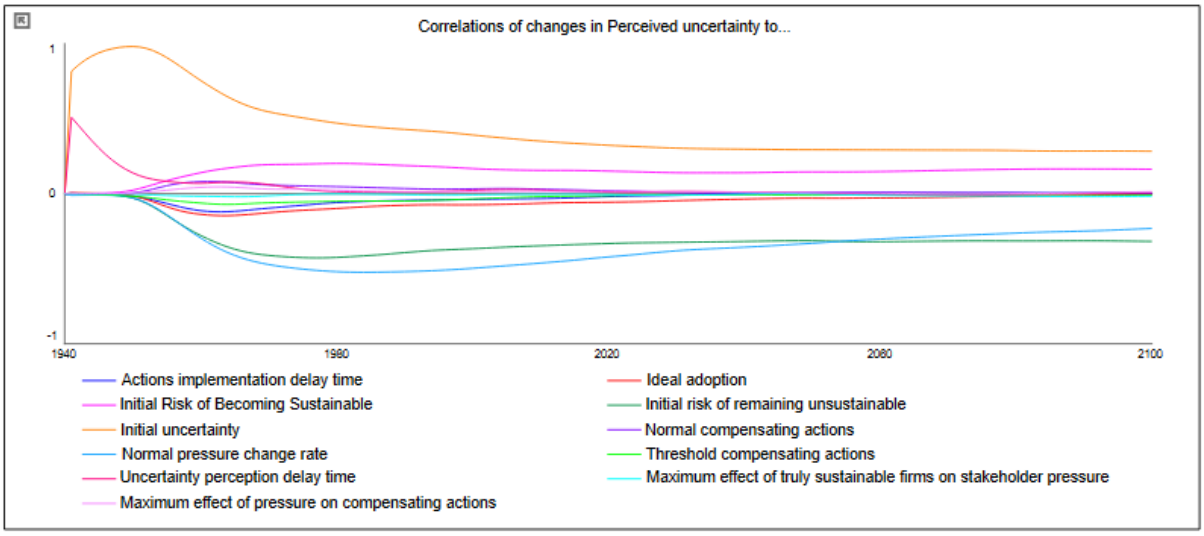
The model produces a range of Perceived uncertainty from 0 to 0.827 uncertainty by 2100, see the figure below. Again, it is not surprising that the confidence interval is so great, as the Local Sensitivity Analysis showed that the model is very sensitive to its uncertain parameters.



The figure shows two different behavioural patterns: 1) goal-seeking decrease followed by another goal-seeking decrease, and 2) equilibrium. The shape of the double goal-seeking decrease is determined by both the speed at which the KPI decreases, the moment in which the equilibrium between the two goal-seeking decreases starts, and the length of this equilibrium. The speed by which the KPI decreases is dependent on the parameters within the R1 and R2 loops. The stronger the loops, the faster Perceived uncertainty will achieve a value of 0. The moment in which the equilibrium starts is dependent on the Uncertainty perception delay time (the shorter the delay time, the sooner the Perceived uncertainty reaches the Initial uncertainty and achieves temporary equilibrium) and on Initial uncertainty (the higher Initial uncertainty, the sooner it is reached by Perceived uncertainty leading to the equilibrium). The adjustment from Initial perceived uncertainty to Initial uncertainty happens at such an early stage, that it has no effect on the other two KPIs, as the Effect of risk and resistance on adoption has not been activated yet. The variable is activated when the Risk of remaining unsustainable is greater than the Risk of becoming sustainable, which happens later in time when the loop dominance shifts from B1 and R3 to R1 and R2. The length of the equilibrium is determined by the moment in which this dominance shift occurs. Adoption will then start to grow, causing R1 and R2 to activate and reinforce adoption partly through the Effect of truly sustainable firms on uncertainty. Parameters within B1 and R3 are therefore responsible for determining the moment in which Perceived uncertainty starts to decrease. If the dominance shift never occurs, Perceived uncertainty will achieve an equilibrium at the value of Initial uncertainty.

The figure below shows all the possibilities of behaviour of Perceived uncertainty. The figure clearly shows behaviour that differs in speed, start- and end-time of the equilibrium, including the equilibrium at the value of Initial uncertainty.





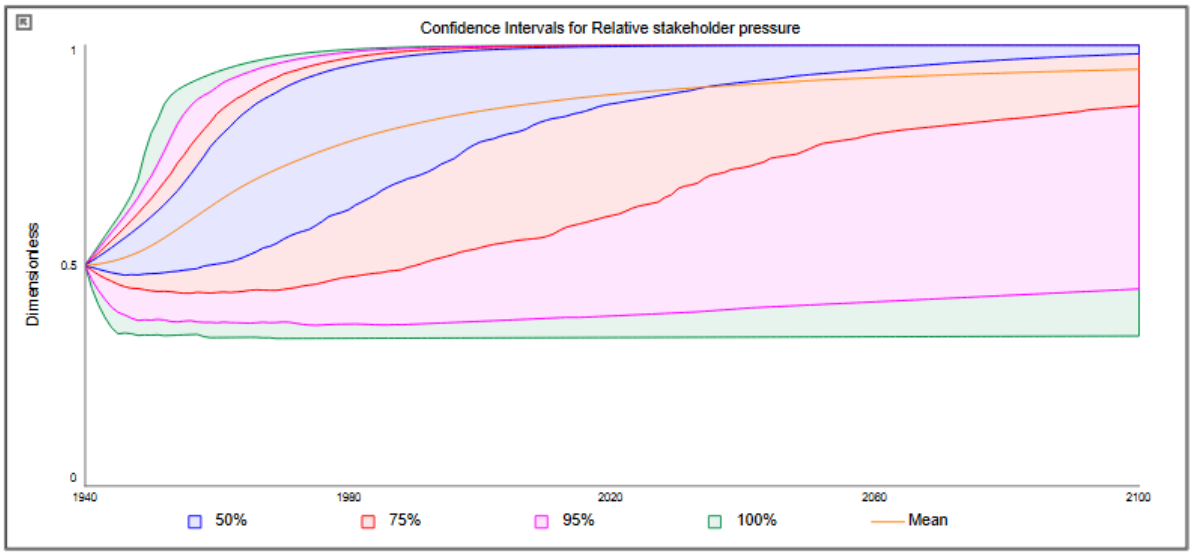
As mentioned above, the R1 loop is initially not activated, which means that most variables in that loop have no effect on Perceived uncertainty, such as Initial risk of becoming sustainable. The initial Perceived uncertainty is however not equal to Initial uncertainty at the beginning of the simulation time, which is why the flow Change in perceived uncertainty is working hard to reach Initial uncertainty. The parameters impacting this flow, Initial uncertainty and Uncertainty perception delay time, are therefore very important for Perceived uncertainty. Initial uncertainty has a maximum impact of 0.982 around 1950, and Uncertainty perception delay time has a maximum impact of 0.509 around 1940. The delay time loses its importance as Perceived uncertainty starts to reach Initial uncertainty. Initial uncertainty remains rather important throughout the whole simulation time, as it heavily influences the input into the flow Change in perceived uncertainty.

The moment that the R1 loop is activated by the shift in dominance from B1 and R3 to R1 and R2, the parameter Initial risk of becoming sustainable starts to become more important with a maximum impact of 0.202 around 1985.

Interestingly, the Initial risk of remaining unsustainable and Normal pressure change rate have a greater correlational effect, with a maximum impact of 0.427 and 0.523 respectively, around 1975. This can be explained by the fact that at the moment of the activation of Effect of risk and resistance on adoption, shortly after the loop dominance shift, the Risk of remaining unsustainable is bigger, thus more dominant in equations, than the Risk of becoming sustainable. Therefore, the Risk of remaining unsustainable, and all concerned parameters (Initial risk of remaining unsustainable and Normal pressure change rate,) have a greater impact on Perceived uncertainty than the parameters affecting Risk of becoming sustainable (Initial risk of becoming sustainable).

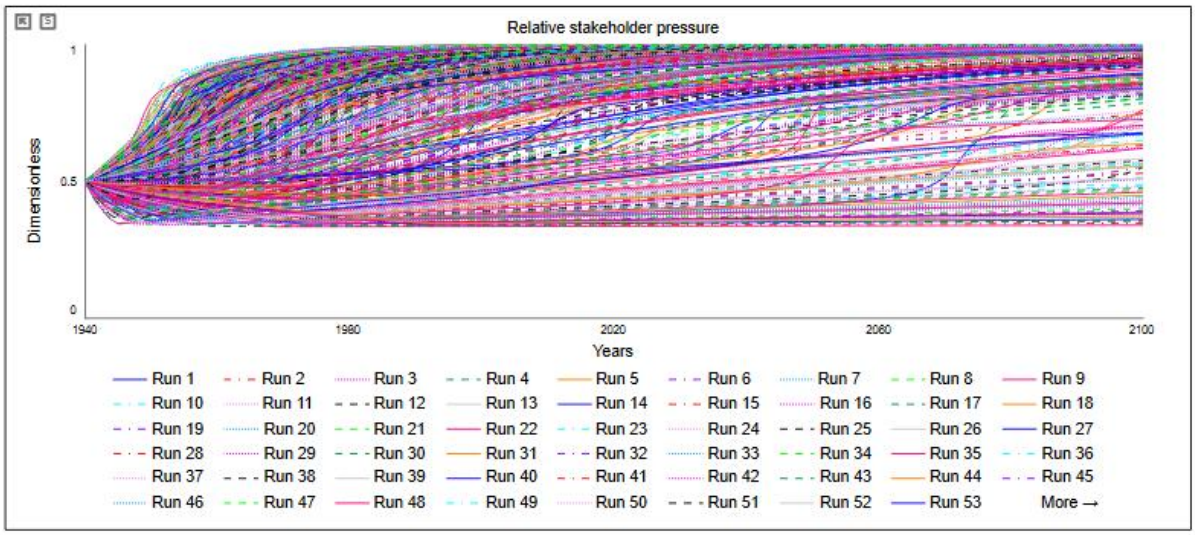
Relative stakeholder pressure

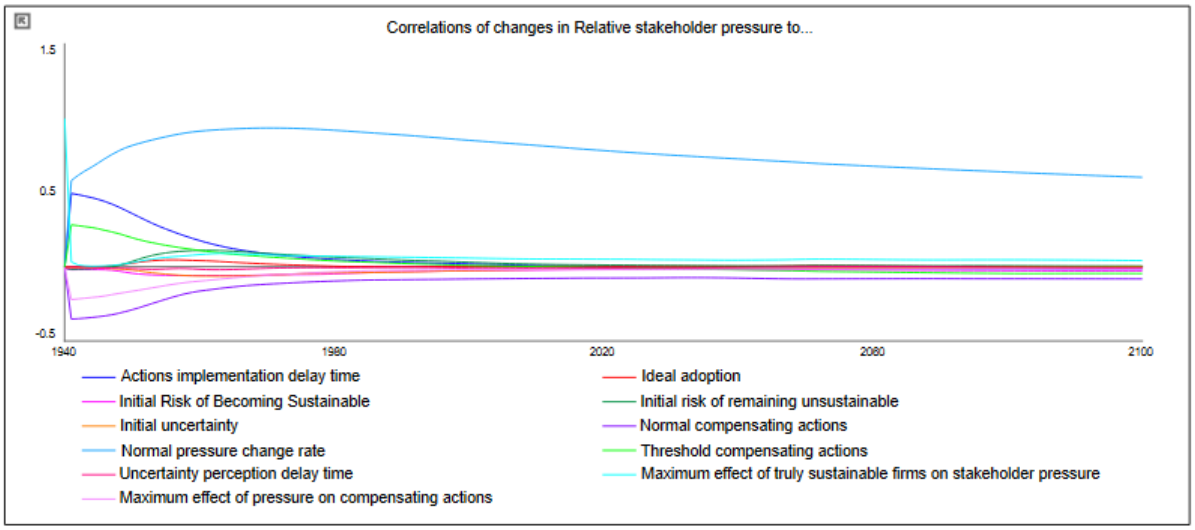
The model produces a range of Relative stakeholder pressure from 0.447 to 1 by 2100, see the figure below. It is still not surprising that the confidence interval is so great, as the Local Sensitivity Analysis showed that the model is very sensitive to its uncertain parameters.



The figure shows three different behavioural patterns: 1) S-shaped increase, 2) decrease followed by an S-shaped increase, and 3) equilibrium. The behaviour is determined by the comparison between the Increase of stakeholder pressure and the Decrease of stakeholder pressure. The Increase of stakeholder pressure is initially fuelled by the Normal pressure change rate and later multiplied by the Effect of truly sustainable firms on stakeholder pressure (R2). The Decrease of stakeholder pressure is entirely fuelled by the Relative compensating actions (B1). If the Increase in stakeholder pressure overpowers the Decrease since the beginning of the simulation time, then the model output will show S-shaped behaviour. If the Decrease is initially greater than the Increase, but is later overpowered again by the Increase, the output will show an initial decrease followed by an increase in Relative stakeholder pressure. Lastly, if the Decrease is constantly greater than the Increase, Relative stakeholder pressure will achieve an equilibrium at a low value.

The figure below shows all the possibilities of behaviour of Relative stakeholder pressure. The figure clearly shows behaviour that differs in speed and start time of the increase, including the equilibrium around 0.4.





As mentioned above, Relative stakeholder pressure is influenced by the B1 loop through Decrease of stakeholder pressure, and by the R2 loop combined with Exogenous growth (Normal pressure change rate) through Increase of stakeholder pressure. Not surprisingly, the most important parameters for Relative stakeholder pressure are: Normal pressure change rate with a maximum impact of 0.937 around 1970; Actions implementation delay time with a maximum impact of 0.506 around 1945; Normal compensating actions with a maximum impact of 0.347 around 1945; Threshold compensating actions with a maximum impact of 0.276 around 1945; and Maximum effect of pressure on compensating actions with a maximum impact of -0.202 around 1945.

It makes sense that the last four parameters, all part of the B1 loop, have their maximum impact at the beginning of the time simulation, decreasing in correlational effect through time. As the B1 loop loses its dominance, the importance of these variables for Relative stakeholder pressure decreases. As the loop dominance shifts, the B1 loop finds an equilibrium because of the limited Effect of compensating actions on stakeholder pressure, which is visible in the figure.

While Absolute decrease of stakeholder pressure comes to an equilibrium, Absolute increase of stakeholder pressure is slowly increasing because of the Normal pressure change rate. The importance of this parameter grows as its own value is growing as well. The figure shows that other parameters' importance starts growing around 1950. These parameters are either part of the R1 loop (Initial risk of becoming sustainable, Initial uncertainty, and Uncertainty perception delay time) or the R2 loop (Initial risk of remaining unsustainable, Maximum effect of truly sustainable firms on stakeholder pressure). Their importance grows as Adoption of true sustainability has started to grow and has activated the R1 and R2 loop.

Interestingly, the figure shows that Relative stakeholder pressure is driven mostly by the exogenous growth variable rather than the endogenous effects on the growth. This is understandable, as the exogenous growth takes a percentage of the simulation time which can take great values, while Effect of compensating actions on stakeholder pressure and Effect of truly sustainable firms on stakeholder pressure are both limited in their maximum effect.

Appendix D: Simulation Experiment Report

Modelling Software: 3.7.1

Integration Method: Euler's Integration Method

DT: 1/32

Time Units: Years

Simulation start time: 1940

Simulation end time: 2100

Base run

SWITCH Government subsidies on compensating actions: 0

SWITCH Critical thinking: 0

SWITCH Awareness: 0

SWITCH Government subsidies adoption: 0

Policy 1: Government subsidies on compensating actions

SWITCH Government subsidies on compensating actions: 1

- ACTIONS IMPLEMENTATION DELAY TIME = 2 (instead of its original value of 4)

SWITCH Critical thinking: 0

SWITCH Awareness: 0

SWITCH Government subsidies adoption: 0

Policy 2: Critical thinking

SWITCH Government subsidies on compensating actions: 0

- Effect of compensating actions on stakeholder pressure = [1 – 1.6] (instead of its original value between [1-2])

SWITCH Critical thinking: 1

SWITCH Awareness: 0

SWITCH Government subsidies adoption: 0

Policy 3: Awareness

SWITCH Government subsidies on compensating actions: 0

SWITCH Critical thinking: 0

SWITCH Awareness: 1

- NORMAL PRESSURE CHANGE RATE = [0.01-0.02] (instead of its original value of 0.01)

SWITCH Government subsidies adoption: 0

Policy 4: Government subsidies adoption

SWITCH Government subsidies on compensating actions: 0

SWITCH Critical thinking: 0

SWITCH Awareness: 0

SWITCH Government subsidies adoption: 1

- Risk of becoming sustainable after policy = Risk of becoming sustainable – [0-0.1] (instead of its original value of Risk of becoming sustainable)

Combination of policy 3 and 4

SWITCH Government subsidies on compensating actions: 0

SWITCH Critical thinking: 0

SWITCH Awareness: 1

- NORMAL PRESSURE CHANGE RATE = [0.01-0.02] (instead of its original value of 0.01)

SWITCH Government subsidies adoption: 1

- Risk of becoming sustainable after policy = Risk of becoming sustainable – [0-0.1] (instead of its original value of Risk of becoming sustainable)