Milestone 149:

Scenario assessment PEP tool for addressing climate change impacts on RWM: a methodology based on interactions with civil society

Work Package 11

Public

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Executive Summary

This Milestone presents the development and update of the **CLIMATE Pathway Evaluation Process (PEP)**, a participatory tool designed within Task 5 of EURAD-2 WP11 CLIMATE to support structured dialogue on the impacts of climate change on radioactive waste management (RWM). The tool aims to facilitate exchanges between technical experts, regulators, research organisations, waste management organisations and civil society, while ensuring balanced participation and allowing different perspectives, concerns and uncertainties to be expressed.

A first version of the CLIMATE PEP was developed through a pluralistic process combining the outcomes of the first CLIMATE workshop in Fontainebleau on 26-27 March 2025, existing PEP methodologies, technical inputs from other CLIMATE tasks, and experience from participatory tools such as the Climate Fresk. This version was tested during the second CLIMATE pluralistic workshop in Liège on 28-29 January 2026. Participant feedback confirmed the relevance of the approach but also highlighted that the combination of numerous cards, climate processes and pathway elements made the exercise overly complex.

The tool was therefore substantially simplified. Climate change processes were integrated directly into a renewed set of Event cards, card texts were shortened and clarified, and the pathway boards were redesigned into two simplified versions: one focusing on high-level waste facilities and one on other RWM facilities. The evaluation cards, discussion methodology and final questions were retained.

The updated PEP was subsequently presented at the CLIMATE Annual Meeting in Caen on 23-24 June 2026 and tested during the EURAD-2 Annual Event in Dublin on 9 September 2026. These applications demonstrated the usefulness of the methodology for exploring the complex interactions between climate change, technical safety, operational constraints and societal dimensions of RWM, while providing a structured framework for pluralistic discussion and mutual understanding.

Keywords

Climate change; Radioactive waste management; Pathway Evaluation Process; Stakeholder engagement; Civil society; Uncertainty; Long-term safety.

Table of content

Table of figures

Glossary

AMOC	Atlantic Meridional Overturning Circulation
CC	Climate Change
DGR	Deep Geological Repository
GHG	Greenhouse Gas(es)
HL	High-Level (waste)
IPCC	Intergovernmental Panel on Climate Change
PEP	Pathway Evaluation Process
RWM	Radioactive Waste Management

Introduction

Within the framework of EURAD-2, the Strategic Study “Impact of climate change on nuclear waste management” (CLIMATE) brought together experts and specialists from 23 organisations from 13 countries representing all colleges and civil society organisations to identify the significant challenges common to the respective National Programmes on this topic. This broad participation gave the WP access to a wide range of disposal concepts, regulatory settings, and climate contexts across Europe, strengthening the relevance of its findings beyond any single national case. The EURAD-2 Work Package (WP) 11 CLIMATE addressed an aspect of growing importance: how climate change may affect the safety and resilience of radioactive waste management facilities over both short and long timescales.

Within the WP, a specific task (Task 5) was dedicated to the interactions with civil society. The main goal of Task 5 was to coordinate the interaction with Civil Society experts (also possibly outside nuclear field) on socio-technical challenges and associated uncertainties, identify stakeholder views related to impacts of climate change on nuclear waste management, foster an efficient collaboration between WP partners, and develop recommendations for transparent information exchange and dialogue with civil society.

To foster this dialogue between stakeholders and enhance the discussions, a specific tool based on a robust methodology already used within EURAD-2, was designed: the PEP tool, standing for Pathway Evaluating Process.

This Milestone presents the process of development of this specific PEP tool designed by NTW within CLIMATE Task 5, tackling the issues of Climate change impacts on RWM.

Presentation of the PEP

The PEP is a participative evaluation exercise designed to help stakeholders:

- Explore and discuss different long-term waste management strategies.
- Identify the concerns and priorities of various actors (waste management organisations, technical support organisations, research entities, civil society, regulators, waste producers).
- Gain a better grasp of the diversity of views present in the room.

Although built as a serious game, the PEP's real value lies in enabling structured pluralistic dialogue. The methodology's core aim is not to determine the “best” solution but to encourage a comprehensive discussion on critical issues and perspectives, particularly among diverse actors, including technical experts and civil society. Several PEPs were designed and used regarding RWM, notably in EURAD-1 WP UMAN and MODATS and in EURAD-2 WP FORSAFF.

The aim is to explore complex or "tricky" issues related to long-term radioactive waste management, ensuring equal participation across stakeholder groups and fostering mutual understanding. The PEP methodology provides an efficient and fair way to surface diverse viewpoints in a non-confrontational setting. The tool helps break down silos between technical, regulatory, and societal actors, promoting collaborative exploration of complex challenges.

The usual methodology is the following: Participants are divided into several small groups (5-7 people) with designated moderators. Discussions are guided by two sets of cards, events and questions related to the events. The cards aim to elaborate concrete cases. These concrete cases are called PEP scenarios, challenging the robustness of two different pathways (strategies retracing the steps of a possible evolution from the current situation of RWM as a whole to a final state called Safe Terminus) represented by a board.

Strict discussion rules apply:

- One participant presents a concrete case he/she elaborated and wants to share.
- Each person speaks in turn, without interruptions, answering the questions addressed by the concrete case.
- After a first round of input, the first participant provides a synthesis of what he or she heard from others.
- A second round allows participants to offer complementary and/or reflective views.

A facilitator (or moderator) ensures equitable participation, creating a respectful, productive dialogue space.

This approach prioritises equality of participation and deepens the collective understanding of each scenario. The focus on equal speaking fosters reflection, ensuring that quieter voices and less-represented concerns are not overlooked.

Figure 1 - How to play the PEP? Example of a scenario: one event card, one or two evaluate cards, a temporal location and a short story about this scenario

In the Task 5 of CLIMATE WP, an ad-hoc PEP game was developed by NTW to strengthen stakeholder engagement in climate change issues linked with RWM. The objective of the development of this tool was to enable structured dialogue on the main challenges and uncertainties related to the impacts of climate change on RWM. A first version of this PEP was used during the second CLIMATE Workshop (28-29 January 2026). Based on the feedback from this session, an updated version was developed and is here presented.

Development of the PEP tool within CLIMATE WP

The CLIMATE PEP game was developed in a pluralistic way.

Its first version was based on several elements:

- The outcomes from the first CLIMATE pluralistic Workshop (26-27 March 2025), and especially on the keynotes presented – and discussed – that gather the views of the different types of actors on the main challenges and uncertainties related to the impacts of climate change on RWM.
- The adaptation of the existing PEP material: several PEP tools were developed on other themes. These versions were reviewed and the relevant elements regarding climate change impacts on RWM were selected.
- The technical inputs from other tasks: Tasks 3 and 4 were invited to provide and review elements, to ensure the technical consistency within the WP.
- The structure and the content of *The Climate Fresk,* an organisation whose aim is to raise public awareness about climate change. It proposes a collaborative serious game using 42 cards where the participants draw a fresco, hence "fresk", which summarises the work of the IPCC. The robust experience of *The Climate Fresk* in the creation of a tool based on collaborative ludic methodology was valuable to structure the development of the CLIMATE PEP.

Several pluralistic discussions on this preparatory work were held within Task 5 members and members from other CLIMATE tasks (e.g. 25 Oct 2025, 16 December 2025). It helped develop, strengthen and review the content of the new PEP tool. Collaborative work was also made possible apart from these meetings, based on a shared document.

This work led to a first version of a PEP tool focusing on Climate Change Impact on RWM. This version was tested during the second CLIMATE pluralistic workshop (28-29 January 2026, Liège).

This first version was based on a non-climate-specific set of cards, that were supposed to be combined with specific newly developed "climate change processes" cards (see Appendix A). A specific board was also developed, allowing the exploration of several elements, facilities and processes linked with RWM.

Figure 2 - Example of the Climate change processes cards

Feedback on the first version of the tool was collected through four final questions that all participants answered at the end of the PEP session. These final questions were:

A. **Climate processes:** Which climate processes concerned you the most in terms of impacts on RWM?

B. **Safety issues:** Which aspects of RWM seem most vulnerable to climate change regarding safety issues?

C. **Mitigation of CC impact on RWM:** How can we improve the mitigation of CC impact on RWM?

D. **PEP experience:** What struck you the most?

This feedback on the content and the methodology of the PEP was crucial, for it helped update the tool. Indeed, some participants to this session stated that even though the methodology and the content was very relevant and useful, the overall session was too complex, being based on too many extensive elements.

After discussions, it was concluded that some updates were indeed needed. Thus, NTW developed a second version of the PEP, notably by:

- Converting the climate change impacts sheets into event cards to simplify the gameplay and to allow participants to really focus on the core topic.
- Reviewing the existing cards to ensure they are relevant and removing them if they were not.

- Simplifying the card text, to improve readability and ease of understanding.
- Simplifying the boards that represent the pathways. It was decided to create two boards, one for high-level waste facilities, and one for other facilities.

Final results

Based on this feedback, two major elements were updated:

- The set of “Event cards” was completely renewed, based on the former “Climate change processes” cards and the existing cards. The final list can be found in Appendix B.
- The boards were simplified, by removing a maximum of confusing elements to improve the “gameplay”. Two boards now exist, one for high-level waste facilities, and another one for other facilities.

The rest of the game, including the methodology, the “Evaluate cards”, and the final questions, were kept identical.

The second version based on this update was presented during the CLIMATE Annual Meeting (23-24 June 2026, Caen) and was used during one of the CLIMATE breakout sessions of the EURAD-2 2026 Annual Event (9 Sept. 2026, Dublin). This session was very fruitful and proved the relevance of the methodology to tackle the complex issue of the impacts of Climate change on RWM facilities. Feedback from participants was collected to improve the tool for future use.

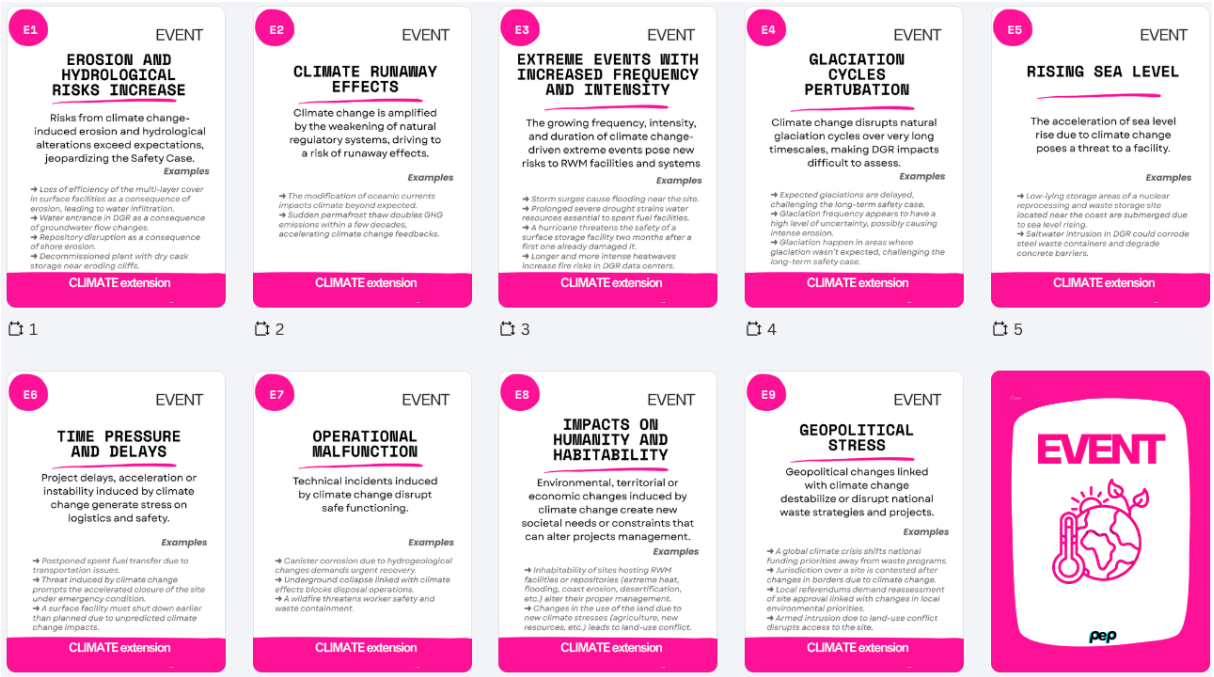

Figure 3 - Example of the updated cards

Date of issue of this report: **24/09/2026**

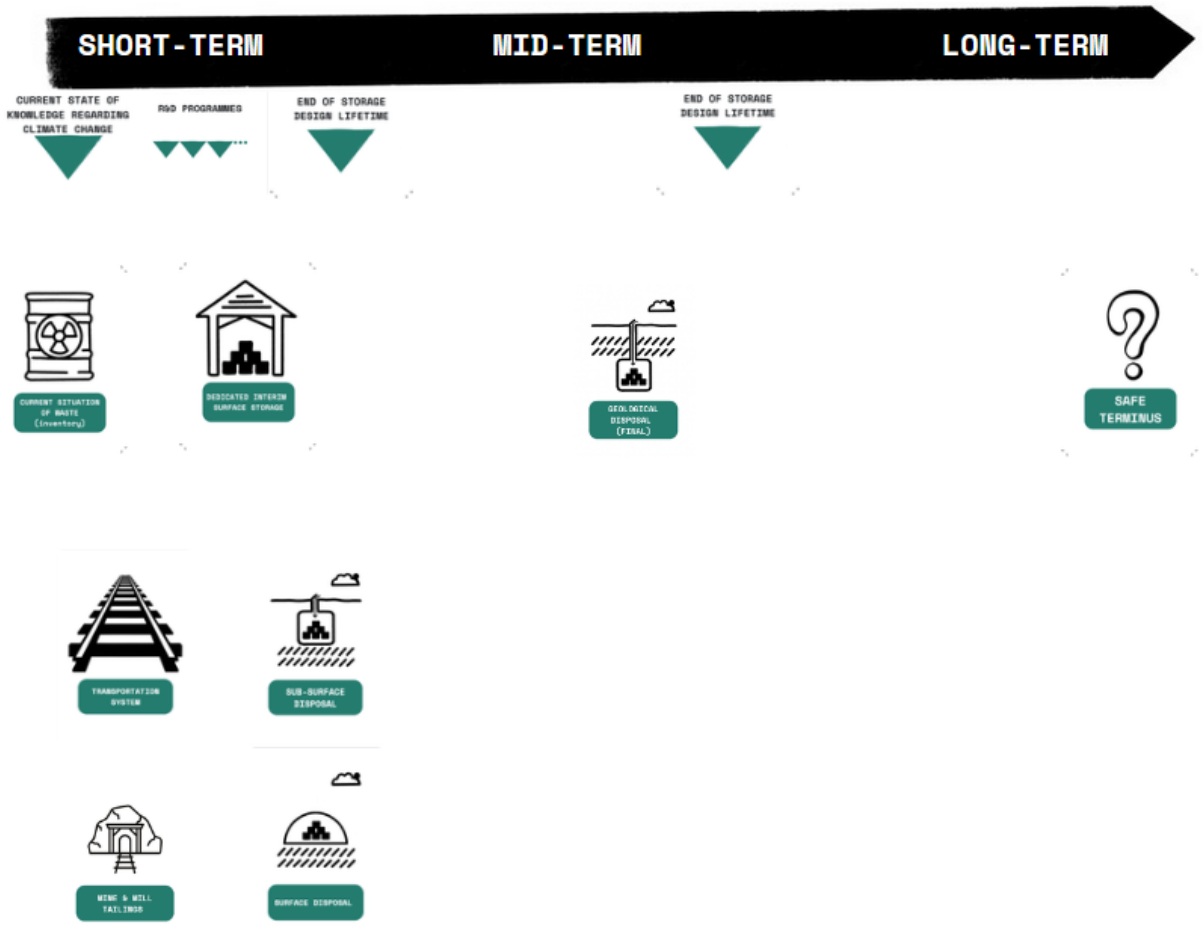

Figure 4 - One of the new board: simplified and easier to use

Conclusion

The development of the CLIMATE PEP provided a practical framework for discussing the ways in which climate change may affect radioactive waste management. Its successive testing and update was made possible through the different CLIMATE events, and the final version is here presented (in Appendix).

The updated version of the tool, based on simplified boards and a renewed set of Event cards, makes it easier to explore the different aspects (technical, operational, environmental and societal) of climate change induced challenges on RWM to foster a discussion based on the PEP methodology and core principles: equal participation, pluralistic discussion and mutual understanding between different categories of stakeholders.

The sessions organised in 2026 also confirmed the relevance of using the PEP as a support for collective reflection on climate-related uncertainties and their implications for RWM strategies and facilities. Further applications of the tool could help refine its content, explore additional scenarios and support future stakeholder dialogue on the impacts of climate change on radioactive waste management infrastructure.

Appendix A. List of the Climate change processes cards

Rising air and water temperatures and ice melting

Rising air and ocean temperatures are driving widespread ice melt — including glaciers and ice caps — disrupting the water cycle and contributing to accelerating sea level rise.

Keywords: temperature rise, perturbed water cycle, ice caps melting, glaciers melting, sea level rise, sea temperature rise

Examples of impacts on RWM:

- Low-lying storage areas of a nuclear reprocessing and waste storage site located near the coast are submerged due to sea level rising.
- Storm surges cause flooding near the site.
- Saltwater intrusion in DGR could corrode steel waste containers and degrade concrete barriers.
- Coastal reprocessing plant at risk from North Atlantic storms.
- Decommissioned plant with dry cask storage near eroding cliffs.
- Floodings compromise retrievability of DG

Increased frequency and intensity of extreme events

Climate change is leading to a measurable increase in the frequency, intensity, and duration of extreme weather and climate events, including heat waves, prolonged droughts, intense precipitation and flooding, stronger hurricanes, large-scale wildfires, and coastal submersion driven by storm surges and sea level rise.

Keywords: heat waves, droughts, hurricanes, fires, floods, submersion, storms.

Examples of impacts on RWM:

- Intense and long-lasting drought stresses the water resources needed for spent fuel facilities
- Two wildfires on the same month impact waste transportation
- A hurricane threatens the safety of a surface storage facility two months after a first one already damaged it
- The increase of duration and intensity of heat waves creates a higher risk of fire in data center of DGR.

Impacts on marine and terrestrial biodiversity

Climate change is profoundly affecting marine and terrestrial biodiversity through ocean temperature rise, ocean acidification, disruptions to calcification processes, shifts in species distributions and behavior, and the combined effects of local extinctions of some species and biological proliferations of others that alter ecosystem structure and functioning.

Keywords: ocean acidification, calcification issues, biodiversity changes in behavior, disappearance and proliferations, biodiversity extinction

Examples of impacts on RWM:

- Algae proliferation near site repeatedly alters cooling systems, delaying cooling time of spent fuel and altering safety.
- Several species near site are threatened by extinction and new environmental impact assessments are needed.
- New flora parasites jeopardize the biological protection envisaged for surface facilities.

Positive feedback loop

Climate change carries a risk of runaway warming driven by positive feedback loops — such as the slowdown of ocean circulation or the thawing of permafrost — which amplify warming by weakening the Earth's natural regulatory systems

Keywords: Gulf Stream slowing down, potential AMOC collapse, permafrost melting

Examples of impacts on RWM:

- The sudden thaw of arctic permafrost multiplies GHG emission by two in only 10 years, accelerating all the CC processes.
- The changes in Atlantic climate systems cause glaciation to occur before the closure of DGR.
- Biodiversity crises severely decrease natural processes of CO2 capture

Impacts on humanity

Climate change is increasingly affecting human societies through the growing scarcity of water resources, declines in agricultural productivity and crop yields, heightened risks to human health, food insecurity and famine, the intensification of climate-induced migration, and the exacerbation of social tensions and armed conflicts.

Keywords: Scarcity of water resources, crop yields loss, starvations, human health, climatic migrations, armed conflicts

Examples of impacts on RWM:

- Inhabitability of some places with RWM facilities / repositories, due to changing climate conditions (extreme heat, floodings, coast erosion, desertification, etc.)
- Change in the use of the land due to new climate stresses (agriculture, new resources, etc.)
- Geopolitical changes linked with climate change: migrations, borders change, conflicts
- Conflict in use of key stressed resources (water) for essential activities: cooling of RadWaste VS agriculture, etc
- Impact of CC on surrounding infrastructures (not directly linked with RWM) but essential for transportation or else

Erosion and hydrological changes

Climate change is driving significant geomorphological and hydrological alterations, including accelerated soil and coastal erosion, shifts in groundwater flow patterns, changes in groundwater chemistry, and, in some regions, increased susceptibility to induced seismic activity.

Keywords: geomorphological and geohydrological impacts - soil erosion, shore erosion, induced seismic activity, groundwater flows changes, groundwater chemical changes.

Examples of impacts on RWM:

- Loss of efficiency of the multi-layer cover in surface facilities as a consequence of erosion, leading to water infiltration
- Water entrance in DGR as a consequence of groundwater flow changes
- Damages to the repository due to CC-induced seismic activity
- Repository disruption as a consequence of shore erosion
- Decommissioned plant with dry cask storage near eroding cliffs.

Very long term impacts on planetary climates

Over very long timescales, climate change can perturb natural glaciation cycles and drive profound alterations of planetary landscapes, reshaping ecosystems and the distribution of sea, ice and landforms across the Earth. These impacts are specifically difficult to predict.

Keywords: glaciation cycles perturbation, landscape changes, issues to predict

Examples of impacts on RWM:

- Repository disruption as a consequence of landscape development (valley creation after changes in river flow)
- Repository flooding as a consequence of severe sea level rise or long-term groundwater level increase
- Glaciation in areas where glaciation wasn't expected
- Delayed glaciation
- Seismic activity/instability/crack formation of DGR, after landscape developments

Appendix B. List of the updated Event cards

E1 – EROSION AND HYDROLOGICAL RISKS INCREASE

Risks from climate change-induced erosion and hydrological alterations exceed expectations, jeopardizing the Safety Case.

Examples:

- *Loss of efficiency of the multi-layer cover in surface facilities as a consequence of erosion, leading to water infiltration*
- *Water entrance in DGR as a consequence of groundwater flow changes*
- *Repository disruption as a consequence of shore erosion*
- *Decommissioned plant with dry cask storage near eroding cliffs.*

E2 – CLIMATE RUNAWAY EFFECTS

Climate change is amplified by the weakening of natural regulatory systems, driving to a risk of runaway effects.

Examples:

- *The modification of oceanic currents impacts climate beyond expected.*
- *Sudden permafrost thaw doubles GHG emissions within a few decades, accelerating climate change feedbacks.*

E3 – EXTREME EVENTS WITH INCREASED FREQUENCY AND INTENSITY

The growing frequency, intensity, and duration of climate change-driven extreme events pose new risks to RWM facilities and systems

Examples:

- *Storm surges cause flooding near the site.*
- *Prolonged severe drought strains water resources essential to spent fuel facilities.*
- *A hurricane threatens the safety of a surface storage facility two months after a first one already damaged it.*
- *Longer and more intense heatwaves increase fire risks in DGR data centers.*

E4 – GLACIATION CYCLES PERTURBATION

Climate change disrupts natural glaciation cycles over very long timescales, making DGR impacts difficult to assess.

Examples:

- *Expected glaciations are delayed, challenging the long-term safety case.*
- *Glaciation frequency appears to have a high level of uncertainty, possibly causing intense erosion.*
- *Glaciation happens in areas where glaciation wasn't expected, challenging the long-term safety case.*

E5 – RISING SEA LEVEL

The acceleration of sea level rise due to climate change poses a threat to a facility.

Examples:

- *Low-lying storage areas of a nuclear reprocessing and waste storage site located near the coast are submerged due to sea level rising.*
- *Saltwater intrusion in DGR could corrode steel waste containers and degrade concrete barriers*.

E6 – TIME PRESSURE AND DELAYS

Project delays, acceleration or instability induced by climate change generate stress on logistics and safety.

Examples:

- *Postponed spent fuel transfer due to transportation issues.*
- *Threat induced by climate change prompts the accelerated closure of the site under emergency condition.*
- *A surface facility must shut down earlier than planned due to unpredicted climate change impacts.*

E7 – OPERATIONAL MALFUNCTION

Technical incidents induced by climate change disrupt safe functioning.

Examples:

- *Canister corrosion due to hydrogeological changes demands urgent recovery.*
- *Underground collapse linked with climate effects blocks disposal operations.*
- *A wildfire threatens worker safety and waste containment.*

E8 – IMPACTS ON HUMANITY AND HABITABILITY

Environmental, territorial or economic changes induced by climate change create new societal needs or constraints that can alter projects management.

Examples:

- *Inhabitability of sites hosting RWM facilities or repositories (extreme heat, flooding, coast erosion, desertification, etc.) alter their proper management.*
- *Changes in the use of the land due to new climate stresses (agriculture, new resources, etc.) leads to land-use conflict.*

E9 – GEOPOLITICAL STRESS

Geopolitical changes linked with climate change destabilize or disrupt national waste strategies and projects.

Examples:

- *A global climate crisis shifts national funding priorities away from waste programs.*
- *Jurisdiction over a site is contested after changes in borders due to climate change.*
- *Local referendums demand reassessment of site approval linked with changes in local environmental priorities.*
- *Armed intrusion due to land-use conflict disrupts access to the site.*