TOPICAL SESSION 4 – NEAR SURFACE DISPOSAL AND CLIMATE CHANGE

RESULTS OF THE SCREENING OF CLIMATE IMPACTS ON POST-CLOSURE

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TASK 4 OBJECTIVE AND WORKFLOW

- **The objective of Task 4 is to identify knowledge gaps and provide recommendations for future research needs of the impact of climate change on radioactive waste management facilities (surface, near surface and deep geological facilities for LLW, LILW, and HLW) during post-closure phase. The secondary objective of Task 4 is to interact with stakeholders (including civil society) on the findings in Task 4.**
- **Tasks and subtasks**
  - Subtask 0: Screening of cases (see questionnaire)
  - Subtask 1: Regulatory framework
  - Subtask 2a: Climate scenarios
  - Subtask 2b: Gaps and constraints
  - Subtask 2c: Natural analogues
  - Subtask 2d: Evolution of climate risks
  - Subtask 3a: Risk methodology/screening
  - Subtask 3b: Recommendations

SUBTASK 0: SCREENING OF CASES

- **Questionnaire (opened late December 2024 – closed late February 2025)**

SUBTASK 0 – CASE SELECTION

Insert the results from the questionnaire for those cases that are actually used to complete the questionnaire. The questionnaire results can be found here: https://service.projectplace.com/#direct/document/960834327

Country	Case study/site name	Disposal type	Waste type	Current phase
Belgium	Dessel	Surface disposal	LILW-SL	Construction

Case study/site name	Latitude	Longitude	Altitude	Distance to sea
Dessel	51°13'23.4"N	5°04'37.5"E	25 m	60-120 km

Case study/site name	Climate Köppen Geiger/Köppen-Trewartha	Hydrology	Land-use	Landscape
Dessel	Cfb/DO	Perennial, groundwater dominated	Grassland, cropland, heather and built area	Low relief topography, rather flat landscape

Case study/site name	Geology below the facility	Hydrogeology below the facility
Dessel	Sedimentary	Aquifer phreatic

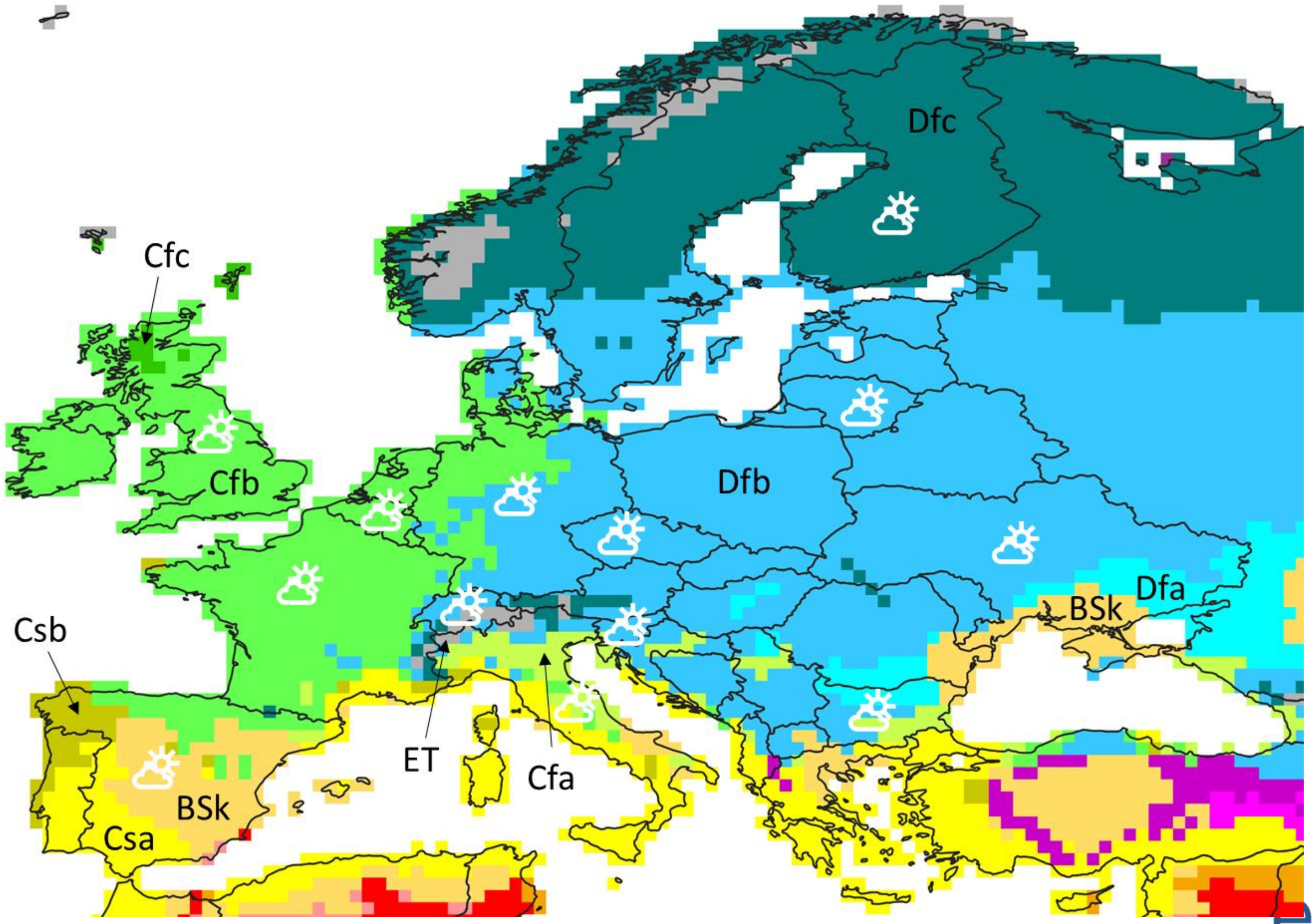
Case study/site name	Pore water below the facility
Dessel	Fresh

Case study/site name	Describe the engineered barriers
Dessel	Multi-layer cover consisting of an earth cover resting on an impervious concrete top slab. The earth cover is 4.5 m thick and consists of a biological layer (sandy loam), a bio-intrusion barrier (coarse inert material), an infiltration barrier (compacted clay) and a drainage layer (sand). The modules and monoliths are made in fiber-reinforced concrete, while the latter are back-filled with mortar.

Case study/site name	References
Dessel	NIROND-TR 2009–07E Version 2. Long-term climate change and effects on disposal facility, geosphere, and biosphere. Project near surface disposal of category A waste at Dessel.

CURRENT CLIMATE: PREFERENCE TO USE KOPPEN-GEIGER CLIMATE CLASSIFICATION

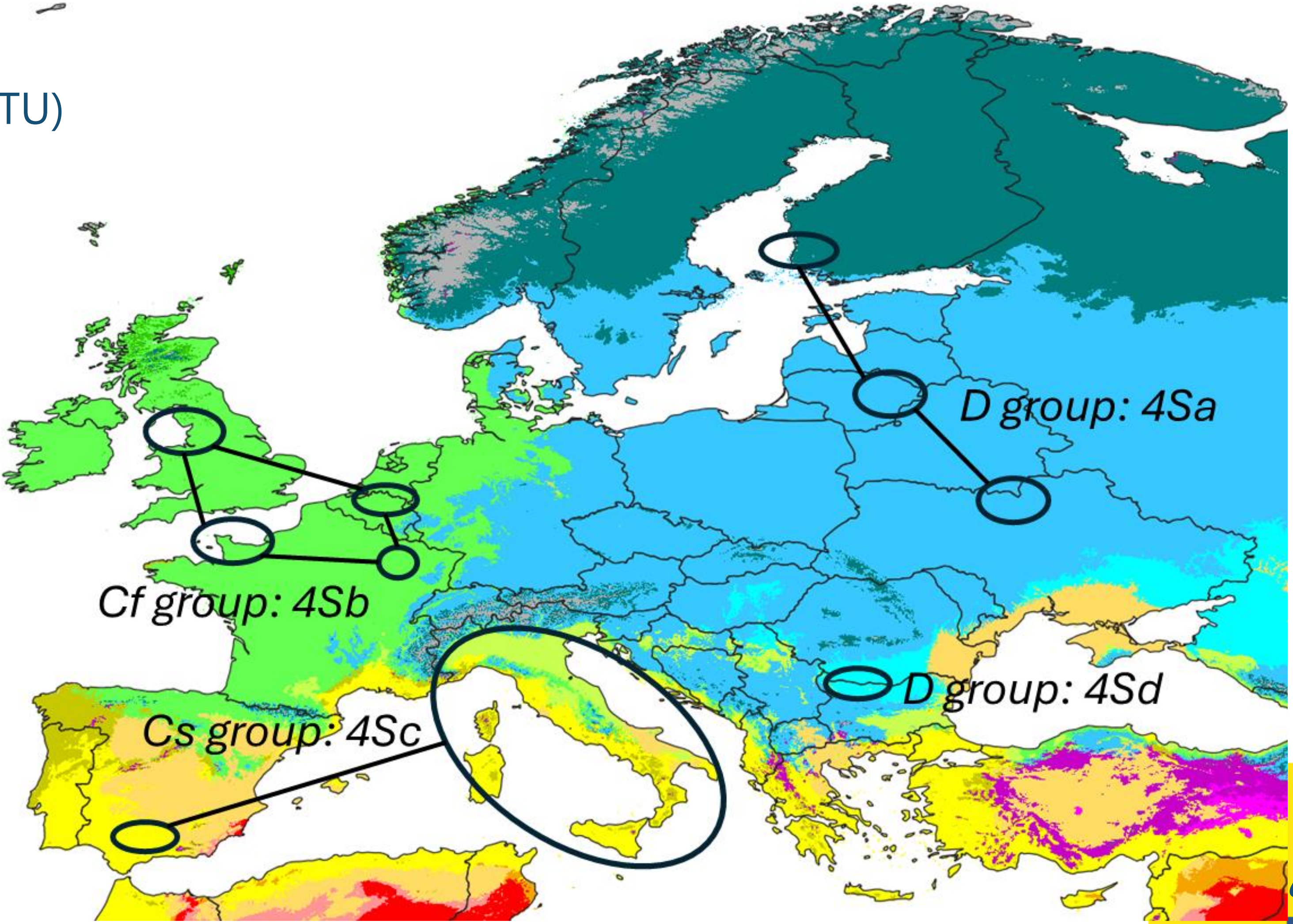
- Af (Tropical, rainforest)
- Am (Tropical, monsoon)
- Aw (Tropical, savannah)
- BWh (Arid, desert, hot)
- BWk (Arid, desert, cold)
- BSh (Arid, steppe, hot)
- BSk (Arid, steppe, cold)
- Csa (Temperate, dry summer, hot summer)
- Csb (Temperate, dry summer, warm summer)
- Csc (Temperate, dry summer, cold summer)
- Cwa (Temperate, dry winter, hot summer)
- Cwb (Temperate, dry winter, warm summer)
- Cwc (Temperate, dry winter, cold summer)
- Cfa (Temperate, no dry season, hot summer)
- Cfb (Temperate, no dry season, warm summer)
- Cfc (Temperate, no dry season, cold summer)
- Dsa (Cold, dry summer, hot summer)
- Dsb (Cold, dry summer, warm summer)
- Dsc (Cold, dry summer, cold summer)
- Dsd (Cold, dry summer, very cold winter)
- Dwa (Cold, dry winter, hot summer)
- Dwb (Cold, dry winter, warm summer)
- Dwc (Cold, dry winter, cold summer)
- Dwd (Cold, dry winter, very cold winter)
- Dfa (Cold, no dry season, hot summer)
- Dfb (Cold, no dry season, warm summer)
- Dfc (Cold, no dry seasoon, cold summer)
- Dfd (Cold, no dry season, very cold winter)
- ET (Polar, tundra)
- EF (Polar, frost)



Beck, H.E., N.E. Zimmermann, T.R. McVicar, N. Vergopolan, A. Berg, E.F. Wood: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Nature Scientific Data, 2018

GROUPING FOR SURFACE DISPOSAL FACILITIES (VLLW, LILW-SL, ILW-SL)

- **D group (4Sa)**
  - Finland (VTT, Mitta, GTK, UTU)
  - Lithuania (FTMC)
  - Ukraine (SSTC)
- **Cf group (4Sb)**
  - Belgium (SCK CEN)
  - UK (NWS)
  - France (Andra, Mines Paris, BRGM, ASNR)
- **Cs group (4Sc)**
  - Spain (Amphos21)
  - Italy (ENEA)
- **D group (4Sd)**
  - Bulgaria (GI-BAS, TUS)



SUMMARY OF INPUT RECEIVED SO FAR

4Sa: Dfb				
Case	Subtask 2a: scenarios	Subtask 2b: gap analysis and constraints	Subtask 2c: natural analogues	Subtask 2d: Evolution of risks
Olkiluoto, F VLLW Applied for operational license Multi-barrier system	Downscaled GCM ensembles Extensions of RCP4.5 and 8.5 (IPCC AR5) 0-1000 yr AP	Contribution of ice-sheets to sea-level rise is highly uncertain in RCP8.5	No	Geosphere: Salt water intrusion Erosion (low risk) Near-field: Erosion of multi-layer cover (low risk due to vegetation) Infiltration (low risk due to hydraulic barrier)
Ignalina, LT VLLW LILW-SL Operation and construction Multi-barrier system	General information SSP scenarios 0-10 kyr AP	Lack of high-resolution locally calibrated climate models GCMs: intrinsic and extrinsic uncertainties No detailed impact modelling available	Climate analogues in regions with Dfa climate (or even Cf climate)	Risk impact (all components) is expected to increase from moderate to very high over the next 10 kyr reflecting progressive decay of (near-)surface engineered barriers from evolving natural conditions and extreme events
ENSDF-3, UA LILW-SL Operation Multi-barrier system	Global model RCP4.5 RCP8.5 0-1000 yr AP >1000 yr AP	Uncertainties in downscaling Palaeo-climate cycles poorly represented No pure analogues for RCP8.5 (Dfa)	Partial analogues are available in NE North-America, but difficult to find for RCP8.5	Geosphere: Increased flooding risk (foundation stability) Near-field: Freeze-thaw/wet-dry -> microcracks -> infiltration Heavy rainfall -> erosivity -> cover Elevated temperatures -> material aging

4Sb: Cfb				
Case	Subtask 2a: scenarios	Subtask 2b: gap analysis and constraints	Subtask 2c: natural analogues	Subtask 2d: Evolution of risks
CSA/CSM, F LILW-SL Operation (CSA) Closure (CSM) Multi-barrier system	Downscaled EMIC (iLoveClim) No emissions RCP8.5 (std + var) 0-1000 yr AP	iLoveClim does not account for all processes (ice-sheets, biochemistry, carbon cycle, land use etc...) Downscaling techniques often yield non-meaningful results Climate predictions with caution Describing climate change with climate classes is often not sufficient (monthly P and T is better)	Future global warming climate data: NW Spain for CSM and S Spain for CSA Erosion: Spain and USA	In all cases: increased erosivity (less rainfall but more intense and degrading vegetation) cause erosion of the cover (increased risk)
Dessel, B LILW-SL Construction Multi-barrier system	GCM ensemble (downscaled) SRES scenarios (IPCC AR4) 0-100 yr AP 0-10+ kyr AP* *BIOCLIM: see 4DGRc	SRES is outdated and replaced by RCPs and even SSPs (IPCC AR6) Analogue climate stations do not match geosphere conditions	Future climate data from analogue stations Soils & palaeosoils for long-term evolution of the multi-layer cover (infiltration) Surficial clay soils in analogue climates Concrete bunkers (WOII) for concrete structures	Geosphere: Low/no risk from hydrogeological changes (lower groundwater table) Saline water intrusion if strong sea-level rise Tidal currents (erosion of cover) Near-field: Increased infiltration to the barrier (low/no risk) Freeze-thaw/wet-dry -> microcracks -> infiltration Heavy rainfall -> erosivity -> cover stability Corrosion of engineered components if saline water
LLWR, UK LLW (ILW) Operational Multi-barrier system	(Model?) SSP1-2.6 SSP2-4.5 SSP5-8.5 0-10 kyr AP	Rate of GHG emission is unpredictable and will always remain uncertain Simplifications to reduce modelling burden	No	No data yet

4Sc: Csa				
Case	Subtask 2a: scenarios	Subtask 2b: gap analysis and constraints	Subtask 2c: natural analogues	Subtask 2d: Evolution of risks
Deposito Nazionale, IT LLW ILW-SL Site selection Multi-barrier system	Generic data RCP4.5 RCP8.5 0-100 yr AP	General considerations only Lack of site-specific data, historical data Propagation of uncertainties Unlikely to predict future GHG emissions with certainty Future scenarios have not been identified formally because there is no site yet	Not yet	Geosphere: Increased ET affects groundwater chemistry (underground components) Precipitation extremes cause flooding events (entire facility) Groundwater flow paths (radionuclides) Near-field: Extreme precipitation events
El Cabril, ES VLLW LILW Operational Multi-barrier system	Business as usual* General estimates** *0-100 yr AP **0-2 kyr AP	Localized future climate and impact scenarios are missing	Potential analogues for BSk/BSh climate	Near-field: T-fluctuations and RH may impact vault walls: low/no risk

4Sd: Dfa				
Case	Subtask 2a: scenarios	Subtask 2b: gap analysis and constraints	Subtask 2c: natural analogues	Subtask 2d: Evolution of risks
Radiana, BG LILW-SL Construction Multi-barrier system	Multi-model ensembles RCP4.5 RCP8.5 0-100 yr AP 0.1-10 kyr AP* *assuming similar conditions as 0-100 yr	Climate models for the period 0.1-10 kyr AP need to be developed	Loess-palaeosol sequences to identify past geohazards for the future	Increased risk for extreme precipitation events, extreme droughts, storms and fire (all components)

GROUP 4S

Group 4Sa (Dfb-climate)	Highlights
2a: scenarios	Downscaled GCM results available
2b: gaps and constraints	Lack of high-resolution locally calibrated climate models, intrinsic and extrinsic model uncertainties, palaeo-climate cycles poorly represented, climate analogues only partially representative
2c: natural analogues	Climate data from analogue climatic stations
2d: evolution of risks	Geosphere: sea-level rise (salt water intrusion) Near-field: erosion of multi-layer cover, flooding risk (foundation), material aging (freeze/thaw, wet/dry, heatwaves)

Group 4Sb (Cfb-climate)	Highlights
2a: scenarios	Downscaled EMIC/GCM output available
2b: gaps and constraints	Outdated GHG emission scenarios (AR4), uncertainties related to GHG emissions, model simplification to reduce computing time, uncertainties related to downscaling, analogue climate data often do not match geosphere conditions
2c: natural analogues	Climate data from analogous stations, soils and palaeosoils for multi-layer cover performance in current or analogue climates, concrete structures
2d: evolution of risks	Geosphere: hydrogeological changes Near-field: increased erosivity of rainfall (erosion), sea level rise (salt water intrusion, marine erosion, corrosion of engineered SSCs)

Group 4Sc (Csa-climate)	Highlights
2a: scenarios	Downscaled global climate model output available for 0-100 yrs
2b: gaps and constraints	Localized future climate scenarios are lacking (>100 yrs AP), lack of site-specific data, GHG emission scenarios
2c: natural analogues	Potential analogues for BSk/BSh climate
2d: evolution of risks	Geosphere: groundwater flow paths, geochemistry, flooding Near field: extreme precipitation events (erosion)

Group 4Sd (Dfa-climate)	Highlights
2a: scenarios	Generic multi-model ensembles available
2b: gaps and constraints	Climate models not available for the period after 100 yrs
2c: natural analogues	Loess-palaeosol sequences for identifying climate-related geohazards
2d: evolution of risks	Increased risk for extreme precipitation events, storms, droughts and fire

SUBTASK 1: CLIMATE CHANGE IN REGULATORY FRAMEWORK

Country	Disposal type	Detailed guidelines (e.g., which models, which climatic situations)	General instructions (e.g., which components of climate change)	Explicitly mentioned but no further details	Implicitly mentioned
UK	S	X			
Spain	S			X	
Bulgaria	S				X
Ukraine	S	X			
Belgium	S			X	
Italy	S				X
Lithuania	S				
France	S				

SUBTASK 2A: CLIMATE SCENARIOS

- **Climate scenario derivation**
  - Based on output from purpose-applied GCMs or EMICs (4Sa, 4Sb)
  - Based on publicly available model output (4Sd)
  - Based on past climate records (4Sc)
- **Future climates**
  - Current Df climates become warmer over the next 100-1000 years
  - Current Cfb climates evolve towards an alternation of Cf(a,b) and Cs(a,b) climates over the next 100-1000 years (temperate/subtropical)
  - Current Csa climates see BSh or BSk conditions (semi-arid) over the next 1000 years

SUBTASK 2B: GAPS AND CONSTRAINTS

- **Uncertainties with respect to GHG emission scenarios (all climates, all time windows)**
- **Outdated GHG emission scenarios (4Sb)**
- **Uncertainties related to downscaling, intrinsic model uncertainties (4Sb)**
- **Local climate model scenarios for the period >100 yrs AP are lacking (4Sa, 4Sc, 4Sd)**
- **Insufficient past climate proxy data (4Sa)**
- **Natural analogues often not fully representative (4Sa, 4Sb)**

SUBTASK 2C: NATURAL ANALOGUES

- **Climate data from analogue climate stations (4Sa, 4Sb, 4Sc)**

- **Geosphere and multi-layer cover**
  - From past geological records in analogue climates (4Sb, 4Sd)

SUBTASK 2D: EVOLUTION OF CLIMATE RISKS

- **Sea-level rise and intrusion of saline water in geosphere/near-field (impact on hydrogeology, hydrochemistry, concrete SSCs: 4Sa, 4Sb, (4Sc)**

- **Flooding of the facility: 4Sa**

- **Mechanical stability of the multi-layer cover (e.g., erosion)**
  - Freeze-thaw/wet-dry: 4Sa, 4Sb, 4Sc, 4Sd
  - Increased rainfall erosivity in future climates: 4Sa, 4Sb, 4Sc, 4Sd

SUBTASK 3A: RISK METHODOLOGY (TO BE DONE)

- **Evaluation of the climate scenario formulations**

CLIMATE FUTURES FOR GROUPS 4S

Country	Group	Climate class	Scenario	0-x00 yrs AP	x00-x000 yrs AP	x000-x0000 yrs AP	Alternative scenarios	Marine intrusion possible?
Finland	4Sa	Dfb	RCP4.5	Dfb	Dfb	-	-	No
			RCP8.5	Dfb	Dfb	-	-	Yes
Lithuania	4Sa	Dfb	SSP5-8.5	Dfb	Dfa	-	Cfa/Cfb	No
Ukraine	4Sa	Dfb	RCP4.5/8.5	Dfa	Not done yet	-	-	No
UK	4Sb	Cfb	SSP1-2.6	Cfb	Cfa	Cfa	-	Yes
			SSP5-8.5	Cfb	Cfa	Cfa	-	Yes
Belgium	4Sb	Cfb	SRES (AR4)	Cfb	Cfa/Csa	Csa	Cfb	Yes
France CSA	4Sb	Cfb	No emissions	Cfb	Cfb	-	-	No
			RCP8.5 std	Cfb	Csa	-	-	No
			RCP8.5 var	Cfa	Csa	-	-	No
France CSM	4Sb	Csb	No emissions	Csb	Csb	-	-	No
			RCP8.5 std	Csb	Csb	-	-	No
			RCP8.5 var	Csb	Csa	-	-	No
Spain	4Sc	Csa	BAU	BSh	BSh	BSk	-	No
Italy	4Sc	Csa	RCP4.5/8.5	B	Not done yet	Not done yet	-	(?)
Bulgaria	4Sd	Dfa	RCP4.5/8.5	Cfa	Not done yet	Not done yet	-	No

SUBTASK 3B: RECOMMENDATIONS (TO BE DONE)

- **Marine intrusion common for many sites/locations**
  - Global models, no need for downscaling

- **Wide scala of GHG emission scenarios**
  - Explore similar GHG emission scenarios

- **Many different models used**
  - Use one single GCM

- **Difficulties in translation between Köppen-Geiger and Köppen-Trewartha classifications**
  - Rather work with climate states instead of classifications
  - Climate change not always reflected in the climate class

WORKPLAN

- **Finalization of Information Sheets: asap**
  - As much as possible details on the models that were used
  - Also indicate whether the models were purpose-applied or from available general sources
  - Natural analogues: should include for which component of the disposal system it is relevant
  - Evolution of risks: same
- **Completion of the Summary Documents: by end of this month**
  - The summary tables shown today can be used as starting point/guideline
  - Note that Subtask 3 (Risk methodology and recommendations) will only be completed in the Summary Documents (*no need to do this in the Information Sheets*)
- **Cross-correlations per subtask**
  - Still to be decided if need to be separate document, or just write down immediately in the White Paper
- **White Paper and Technical Report: by end of December**