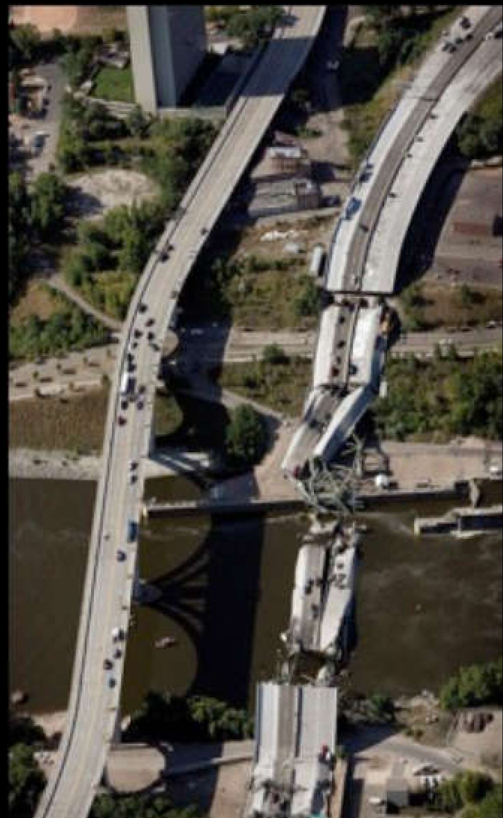
XV International Conference on Durability of Building Materials and Components
DBMC 2020, Barcelona

PRESCRIPTION OF MAINTENANCE INTERVENTIONS BY THE NEW GENERATION OF EUROCODES FOR CLIMATE-CHANGE RESILIENT STRUCTURES

Maria Nogal

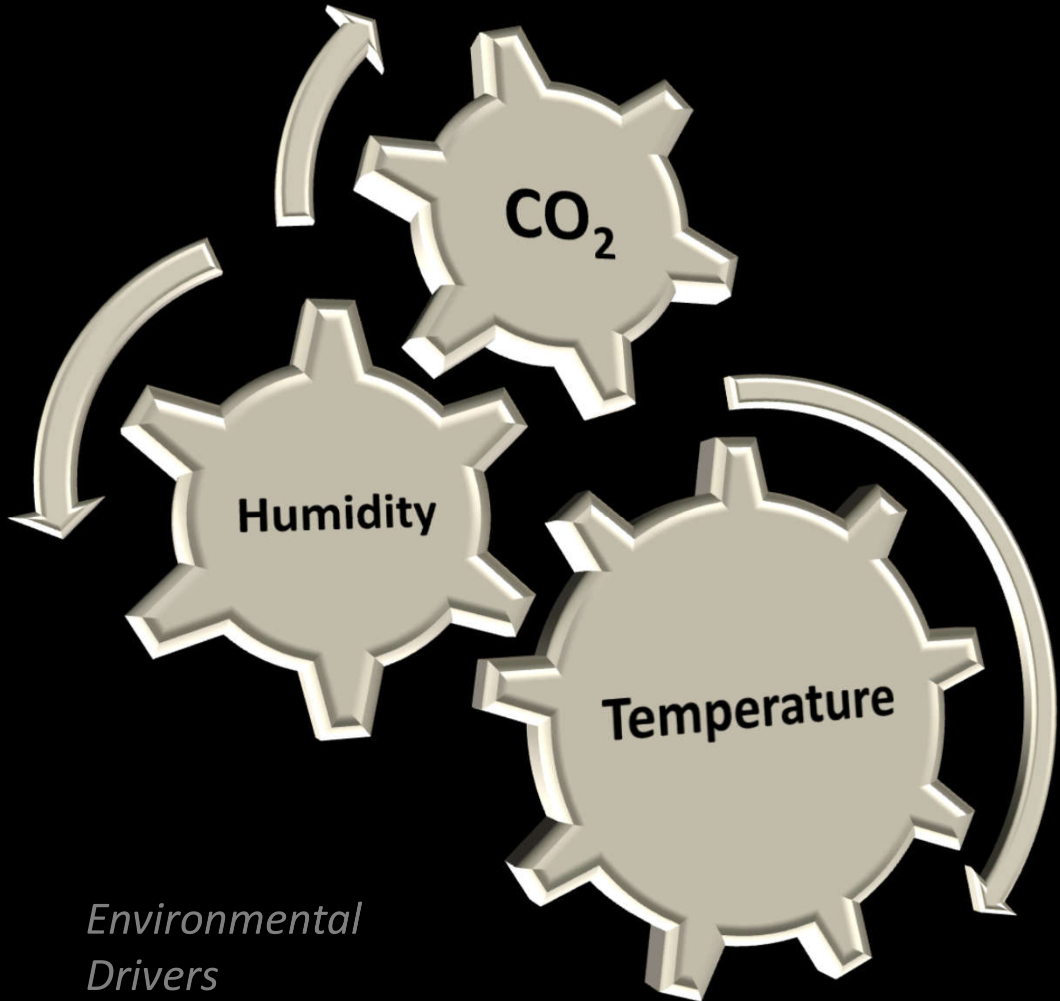
"The acceleration of the corrosion process due to climate change might be of hundreds of billions of dollars annually."*

Highway 35W - Mississippi Bridge (2007)



**Bastidas-Arteaga, E., & Stewart, M. (2015). Damage risks and economic assessment of climate adaptation strategies for design of new concrete structures subject to chloride-induced corrosion. Structural Safety*

Corrosion of Reinforced concrete



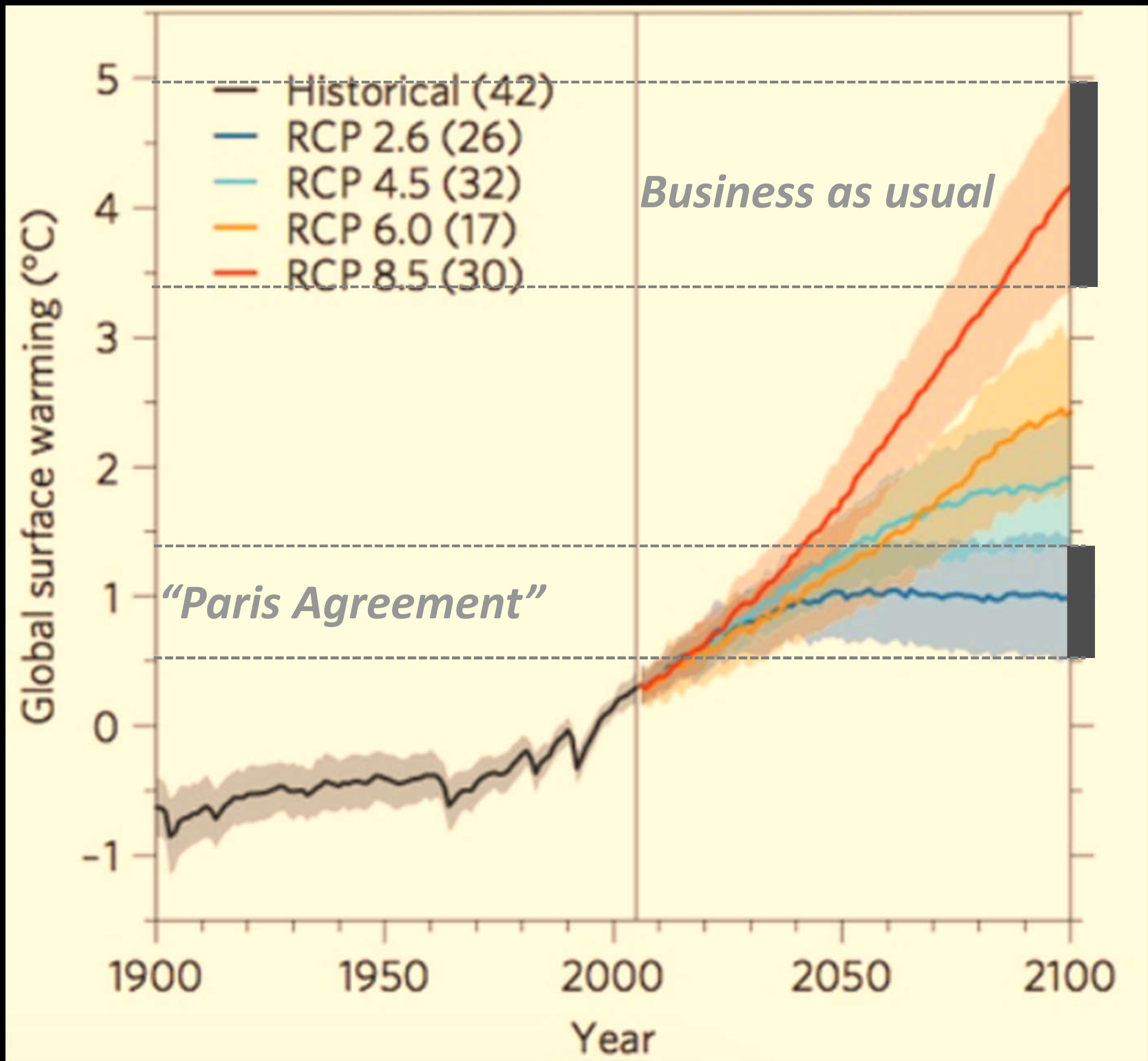
Environmental Drivers

- ✓ Impact of climate change on RC corrosion
- ✓ Roadmap of EC
- ✓ Adaptation challenges

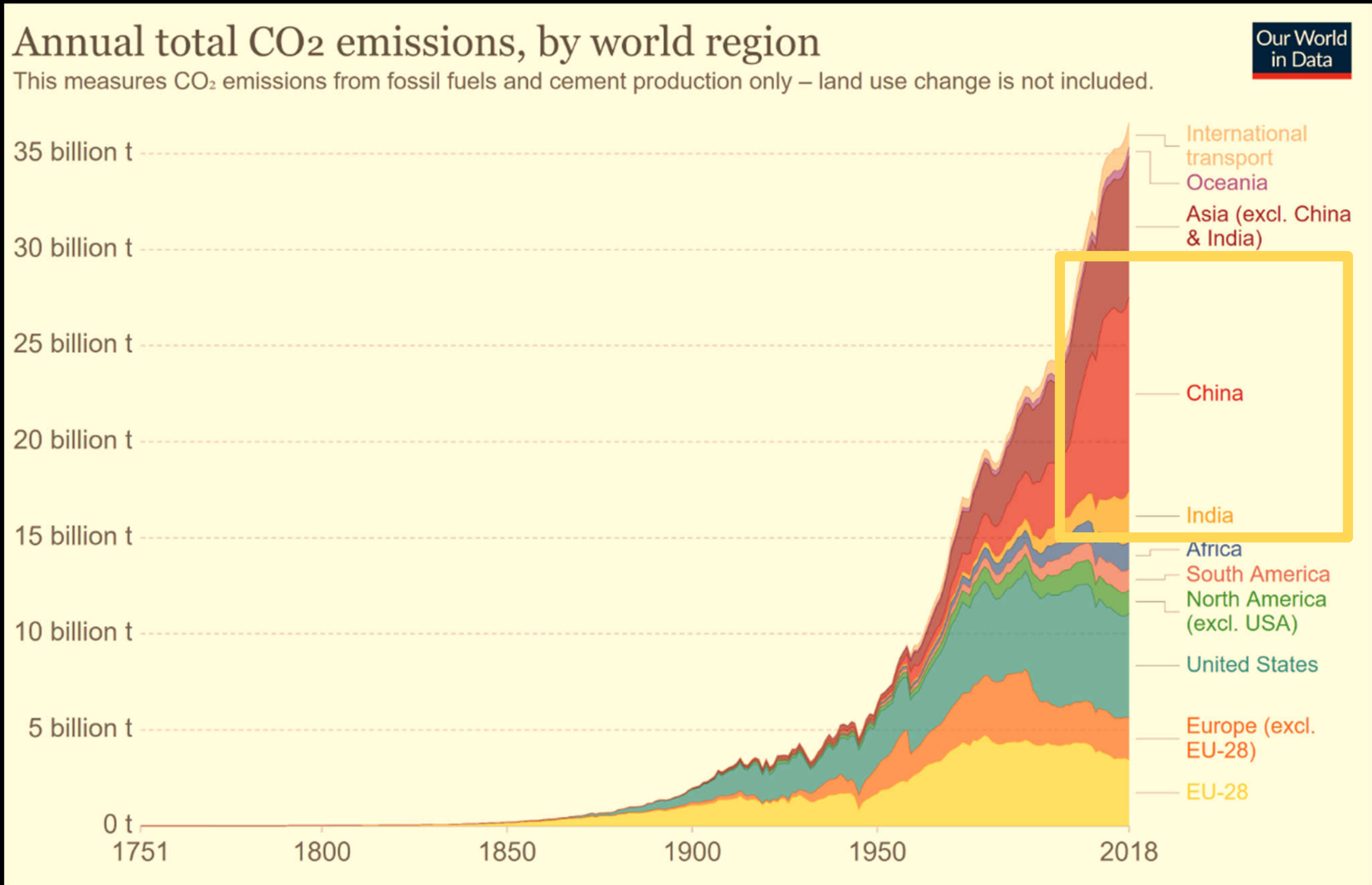
Climate Change

Impact on the environmental drivers

Climate Change Scenarios



Climate Change
Scenarios



Corrosion drivers
Climate proxies

Ambient temperature: Air temperature

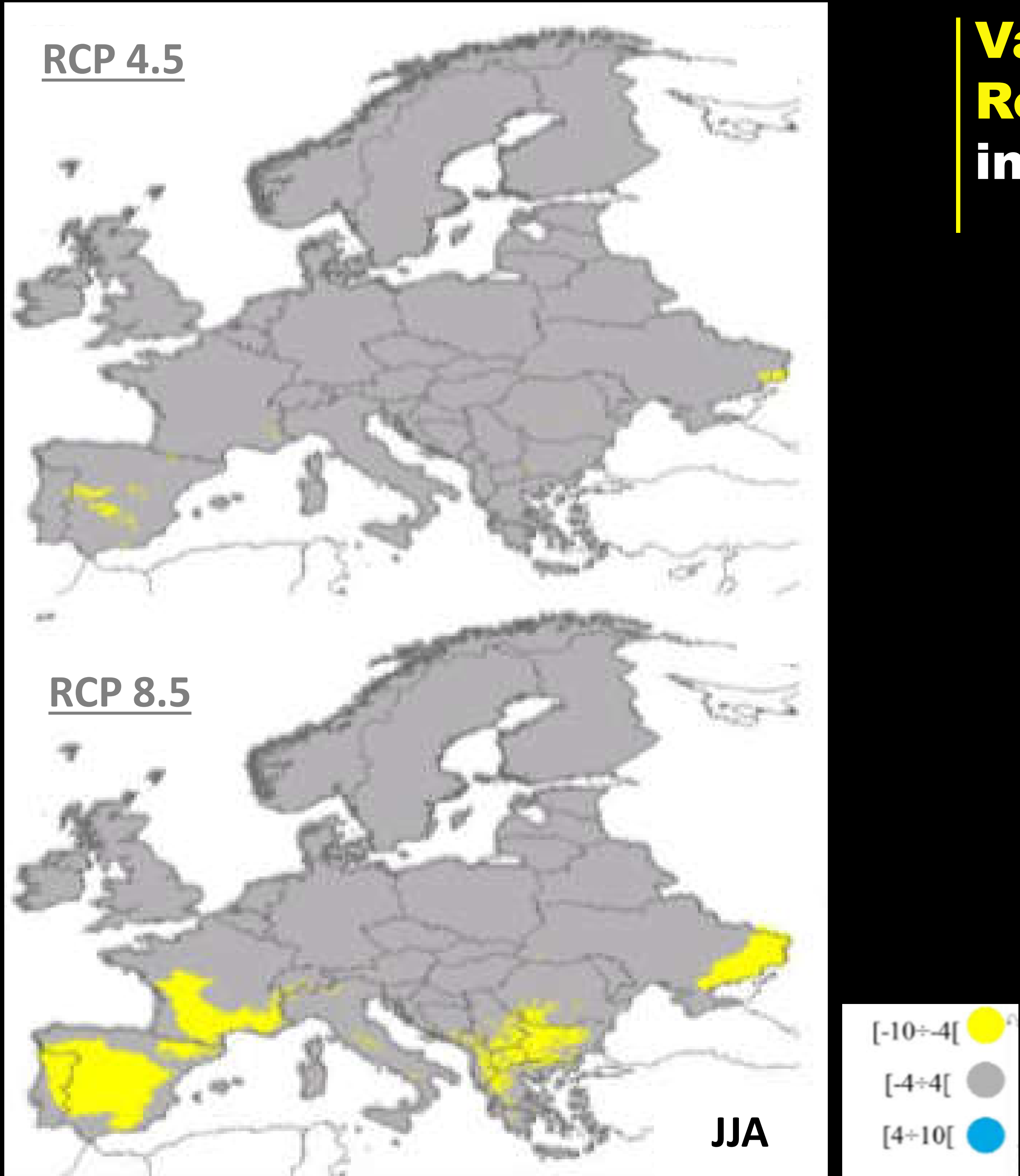
Ambient humidity: Relative humidity

Variation of air temperature in Europe

Area	Winter	Summer	Autumn	Spring
	(DJF)	(JJA)	(SON)	(MAM)
	RPC4.5			
North Europe	2^o-8^o (M)	0^o-6^o (H)	2^o-6^o (H)	2^o-6^o (M)
Central Europe	0^o-4^o (H)	0^o-4^o (H)	0^o-4^o (M)	0^o-2^o (V)
Mediterranean area	0^o-4^o (H)	2^o-4^o (H)	0^o-4^o (H)	0^o-4^o (H)
East Europe	2^o-6^o (H)	0^o-4^o (M)	0^o-4^o (H)	0^o-4^o (H)
	RPC8.5			
North Europe	4^o-10^o (M)	2^o-6^o (H)	2^o-6^o (H)	2^o-8^o (H)
Central Europe	2^o-4^o (V)	2^o-4^o (V)	2^o-6^o (H)	2^o-4^o (H)
Mediterranean area	2^o-4^o (V)	2^o-6^o (M)	2^o-6^o (H)	2^o-4^o (V)
East Europe	2^o-6^o (M)	2^o-6^o (H)	2^o-6^o (H)	2^o-6^o (H)

In brackets, level of agreement among climatic models : L-low, M-medium, H-high, V-very high

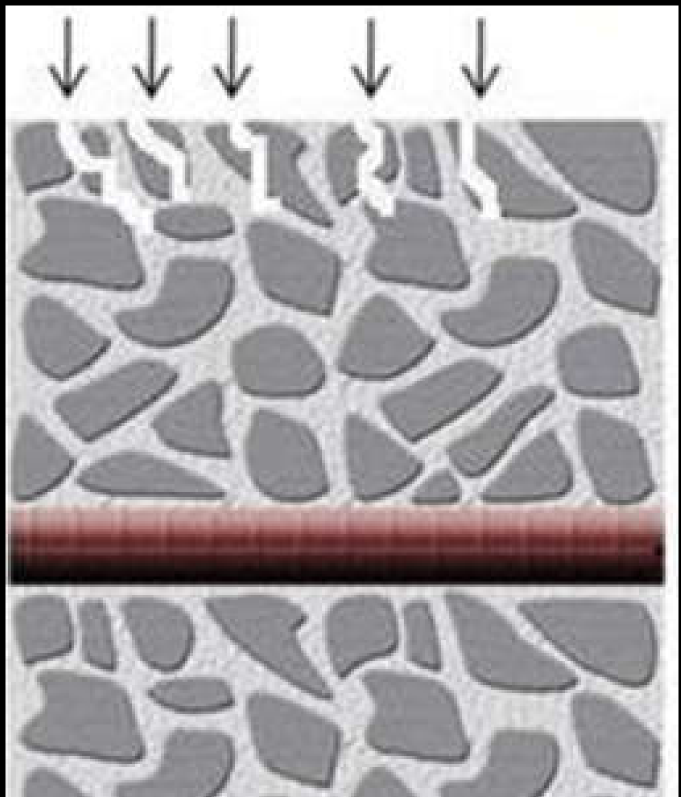
Variation of Relative Humidity in Europe



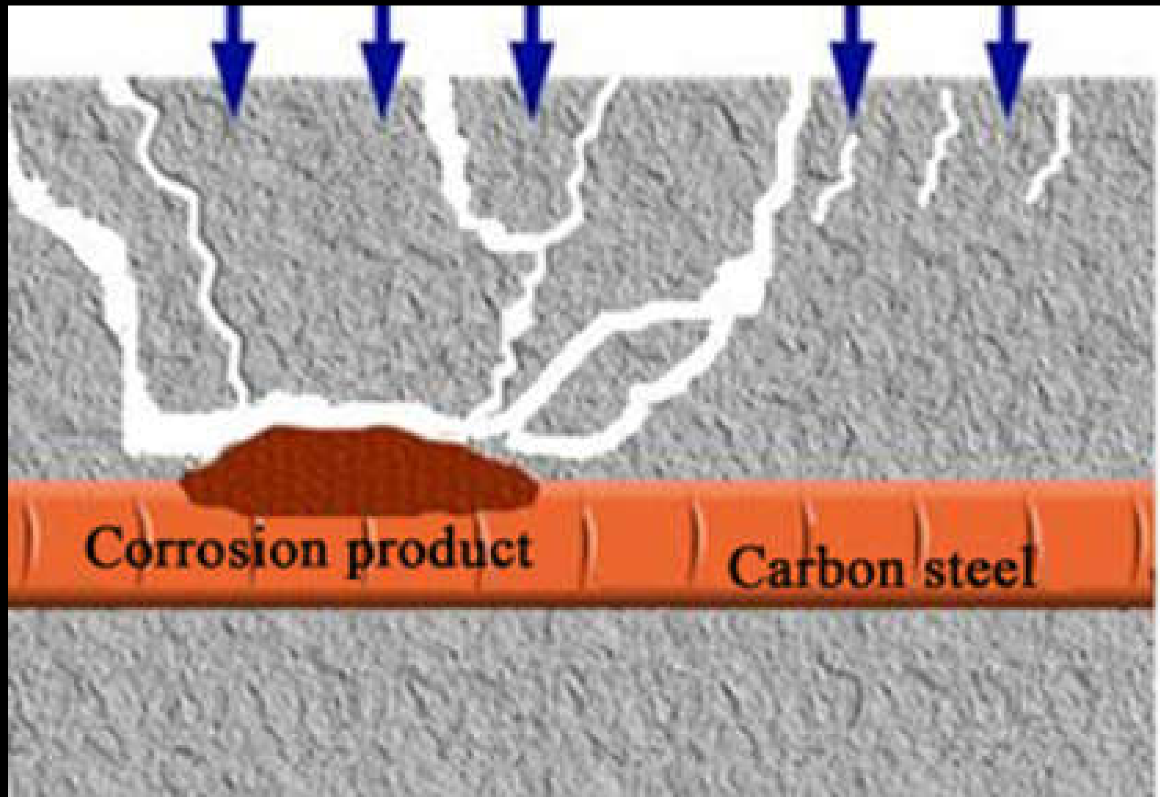
Concrete corrosion. Climate change impact

Reinforced concrete corrosion Mechanism

Initiation stage



Propagation stage



Reinforced concrete corrosion
Processes

Carbonation

CO_2


Chlorination

Chlorides


Initiation stage

Impact of CC on carbonation ingress

Ref.	Location	Assumptions	Estimation		Scenarios	
			Target	Value	Baseline	Target
CARBONATION INGRESS PROCESS						
Talukdar et al. (2012)	Canada	(a) increasing mean yearly temperature, (b) increasing duration of the hot season, (c) constant RH over time, and (d) increasing concentration of CO2	carbonation depths of non-pozzolanic, unloaded concrete structures	increment of 45%	year 2000	A1FI, year 2100
Talukdar & Banthia (2013)	Mumbai, London, New York City, Sydney, Toronto, Vancouver	(a) time dependent temperature	carbonation depths	increments between 27% and 45% (15 and 35 mm)	year 2000	A1FI, year 2100
Saha & Eckelman (2014)	Boston metropolitan area	(a) increasing temperatures, (b) increasing concentrations of CO2	carbonation depths	increment of 40%	year 2000	A1FI, year 2100
Peng & Stewart (2014)	China	(a) CO2 concentration, (b) local temperature, and (c) RH variable over time	carbonation depths	increment of 45%	year 2010	RCP8.5, year 2100
Mizzi et al. (2018)	Malta	(a) increasing CO2 concentration, and (b) increasing temperatures	carbonation depths for different concrete grades	increment up to 40%	RCP 2.6	RCP 8.5, year 2070

Initiation stage

Impact of CC on chlorine ion ingress

Ref.	Location	Assumptions	Estimation		Scenarios	
			Target	Value	Baseline	Target
CHLORINE ION INGRESS PROCESS						
Saha & Eckelman (2014)	Boston metropolitan area	(a) increasing temperatures, (b) increasing concentrations of CO2	chloride penetration depths	increment of 12%	year 2000	A1FI, year 2100
Xie et al. (2018)	China	(a) increasing temperatures	chloride concentration at the rebar level of offshore RC bridges	increments of 6%-15%	year 2000	RCP8.5, year 2100
Khatami & Shafei (2017)	U.S. Midwest region	(a) increasing temperatures, (b) decreasing, constant and increasing RH, and (c) increasing surface chloride concentration	chloride concentration at the rebar level	increment of 37%	RCP2.6, year 2100	RCP8.5, year 2100

*Increment of the consumption of the deicing salts as a consequence of CC: **twice larger in the last 25 years**.*

Initiation stage

Carbonation & chlorination

Compound effect

Impact of CC on Reliability and Service life

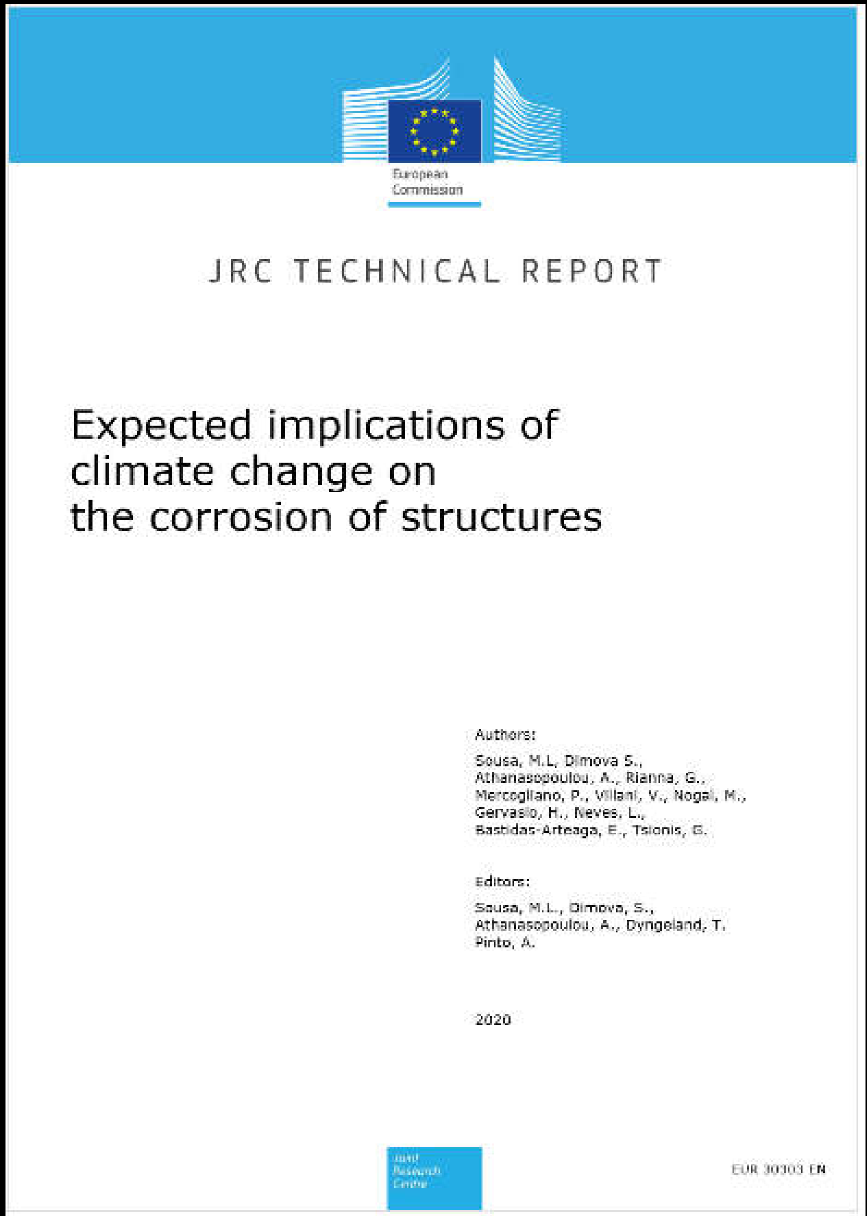
Ref.	Location	Assumptions	Estimation		Scenarios	
			Carbonation-induced	Chloride-induced	Baseline	Target
M. G. Stewart et al. (2011)	Australia	(a) Increased CO2 levels, temperature and humidity, (b) different exposure classifications of the Australian code AS3600 (2009)	Increment of damage risk over 400% for inland arid or temperate climates	Increment of damage risk up to 15%	year 2000	A1B & A1FI, year 2100
Saha & Eckelman (2014)	Boston metropolitan area	(a) Structural design according to ACI (2011)	Reduction of service life of 26 years. Penetration depths in 60% of existing buildings exceeding the recommended cover thickness by 2050.	Reduction of service life of 10 years	year 2000	A1FI, year 2100
Pakkala et al. (2019)	Finland	(a) Changes in ambient T, RH and wind-driven rain, (b) different locations with respect to the solar radiation	Increment of corrosion rates of up to 200% during winter in coastal areas facing to the South		year 2000	A2, year 2100
Bastidas-Arteaga & Stewart (2015)	Continental, oceanic and tropical environments	(a) Increasing temperatures and length of hot periods, and (b) increasing RH	Lifetime reductions ranging up to 18%		year 2000	year 2100

Assessment of problem severity

- Scarce studies in Europe
- Forecasted values of environmental drivers
- Studies linked to the level of confidence
- Structure and building stock database

Adaptation to climate change

Adaptation of European infrastructure to CC


European Commission

JRC TECHNICAL REPORT

Expected implications of climate change on the corrosion of structures

Authors:
Sousa, M.L, Dimova S., Athanasopoulou, A., Rianna, G., Mercogliano, P., Villani, V., Nogal, M., Gervasio, H., Neves, L., Bastidas-Arteaga, E., Tsionis, G.

Editors:
Sousa, M.L., Dimova, S., Athanasopoulou, A., Dyngeland, T. Pinto, A.

2020

Joint Research Centre

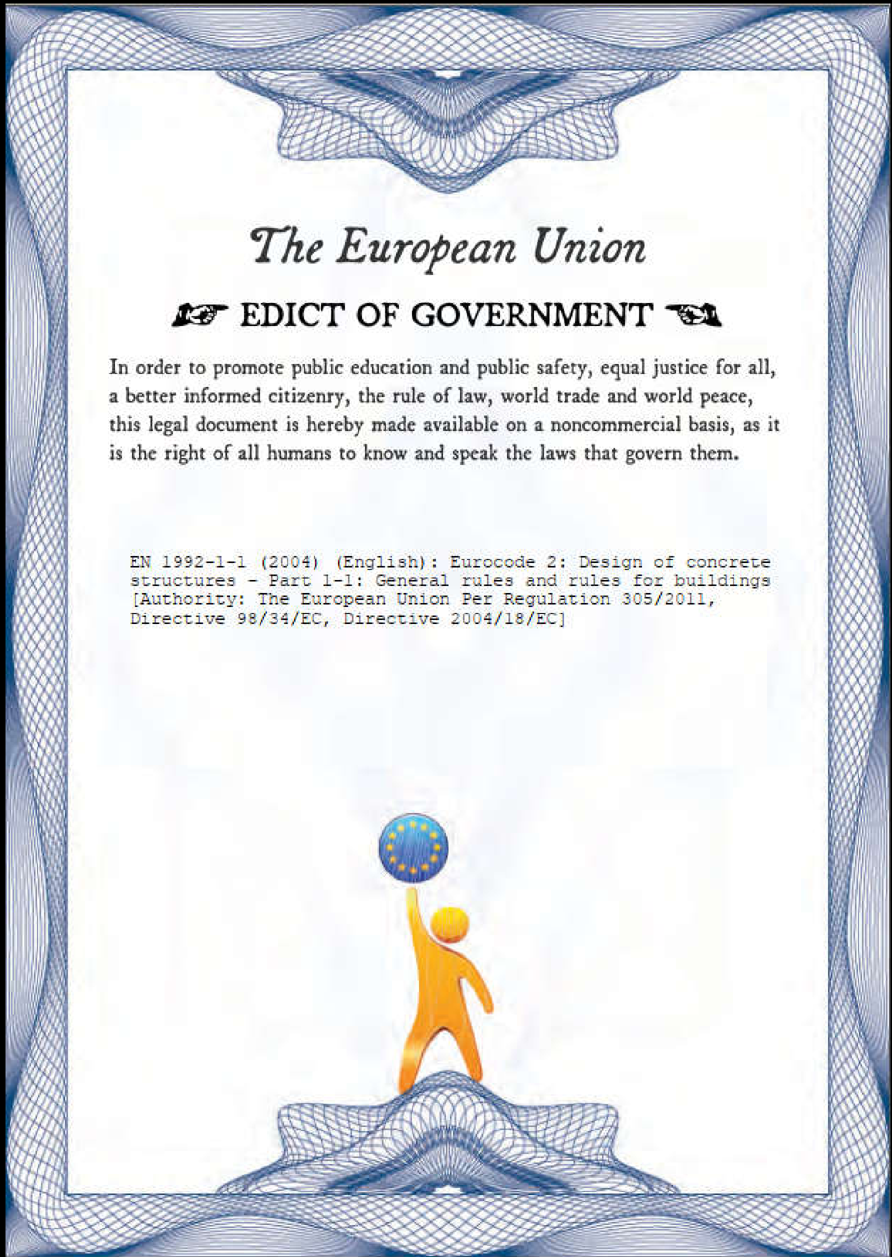
EUR 30303 EN

Technical standards.
New Generation of Eurocodes

Inform and support UE policies and development of standards

Adaptation of European infrastructure to CC

Structural corrosion: **EC2**



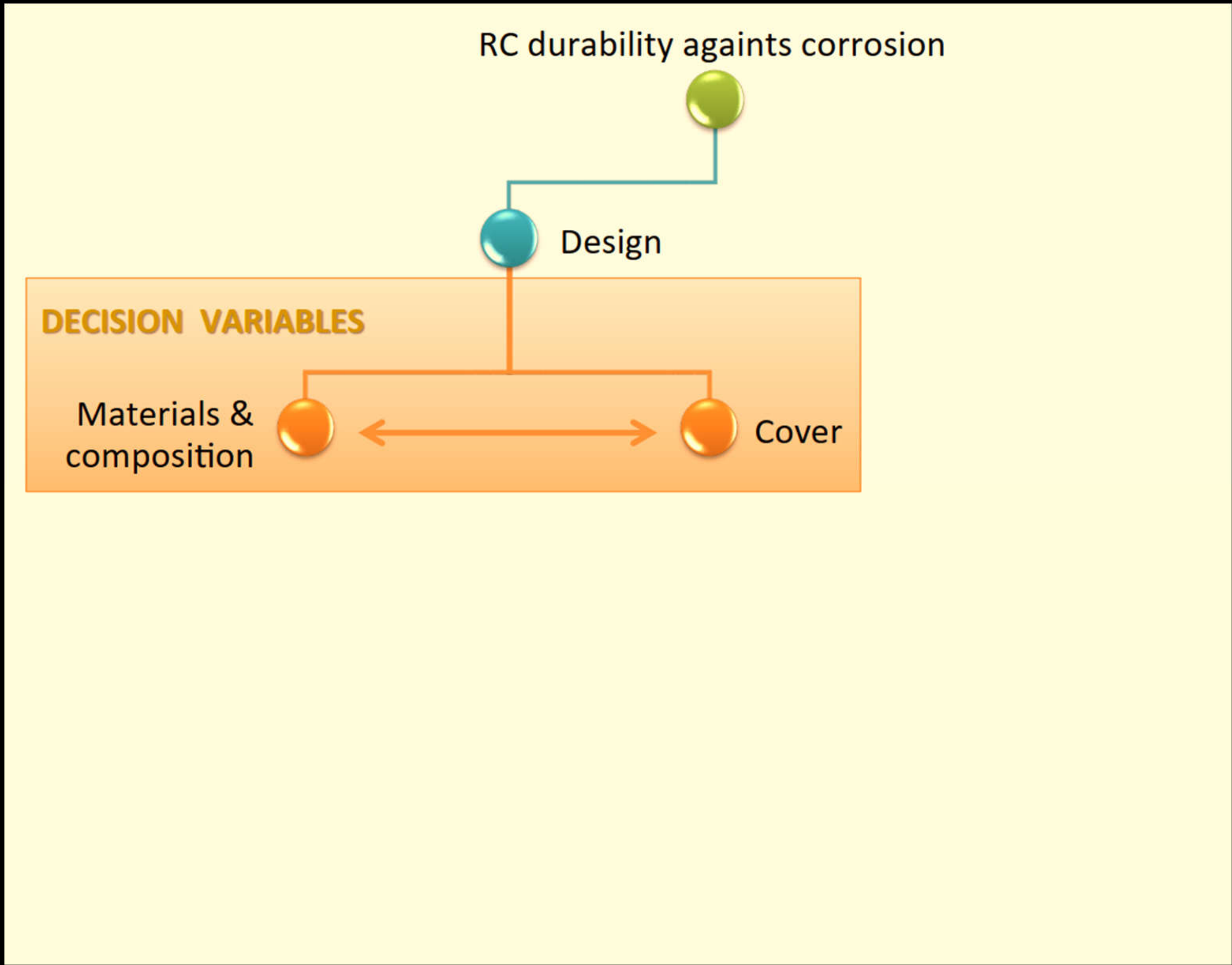
The European Union

EDICT OF GOVERNMENT

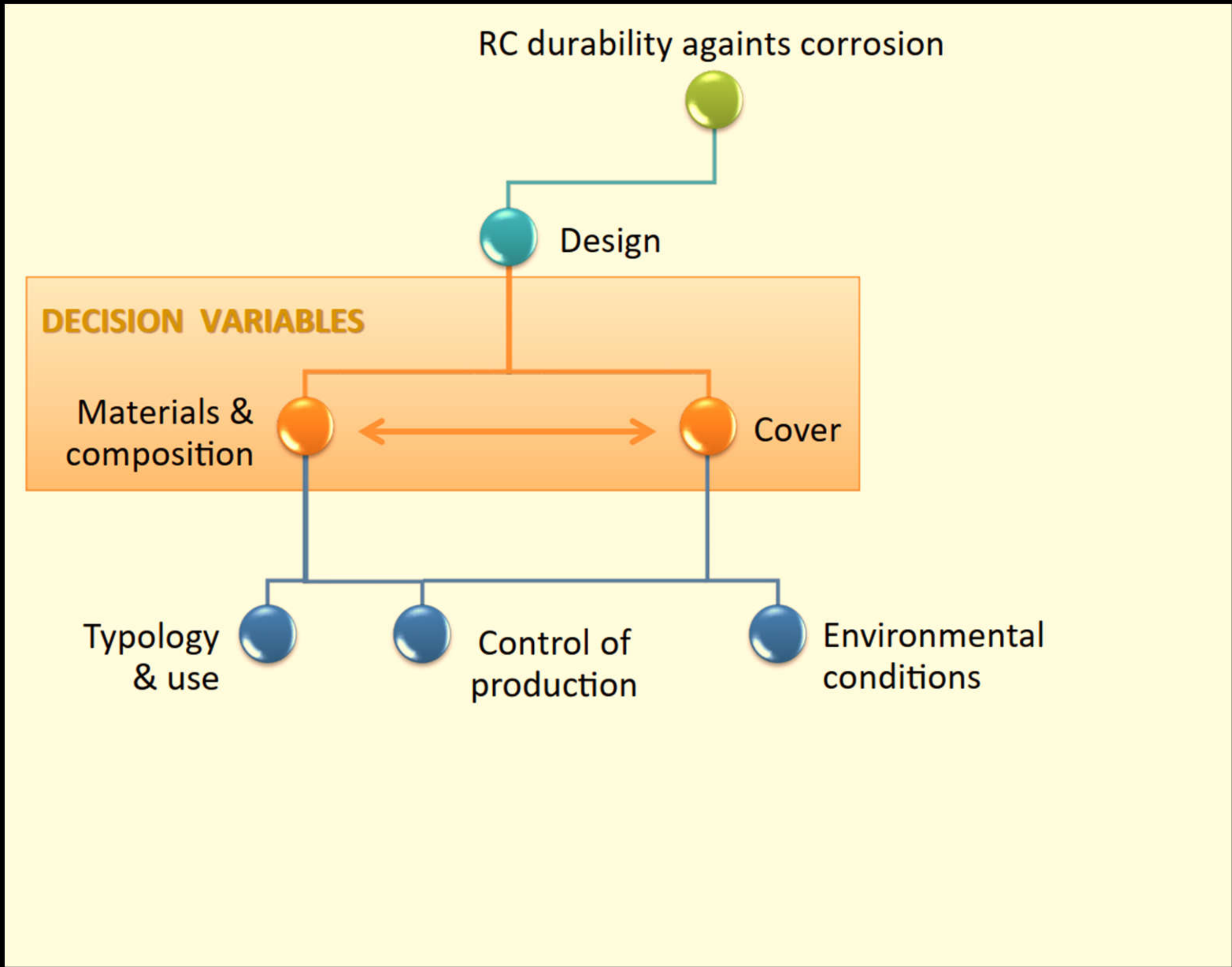
In order to promote public education and public safety, equal justice for all, a better informed citizenry, the rule of law, world trade and world peace, this legal document is hereby made available on a noncommercial basis, as it is the right of all humans to know and speak the laws that govern them.

EN 1992-1-1 (2004) (English): Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]

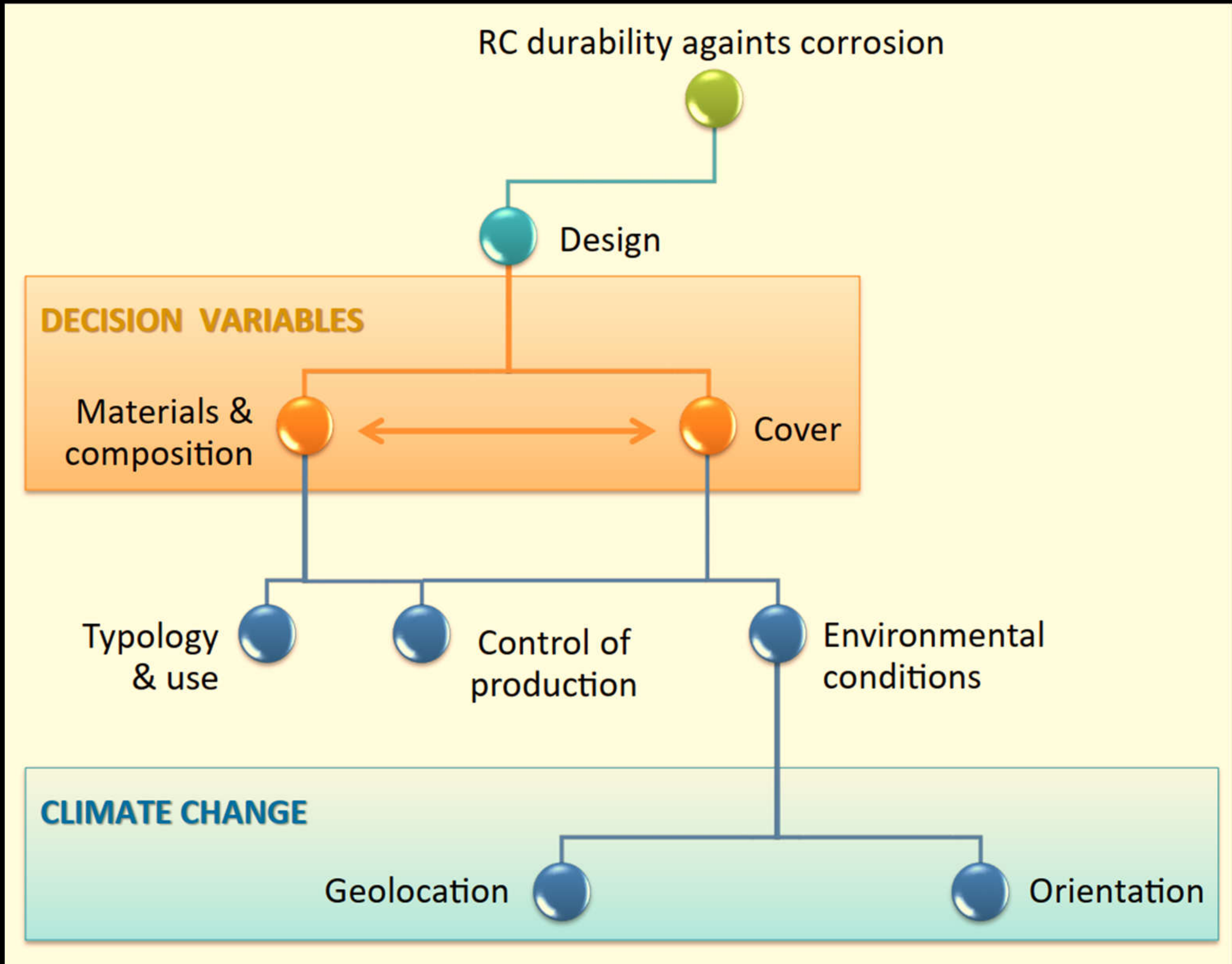
RC durability against corrosion



RC durability against corrosion



RC durability against corrosion



Catholic
protection

Adaptation measures

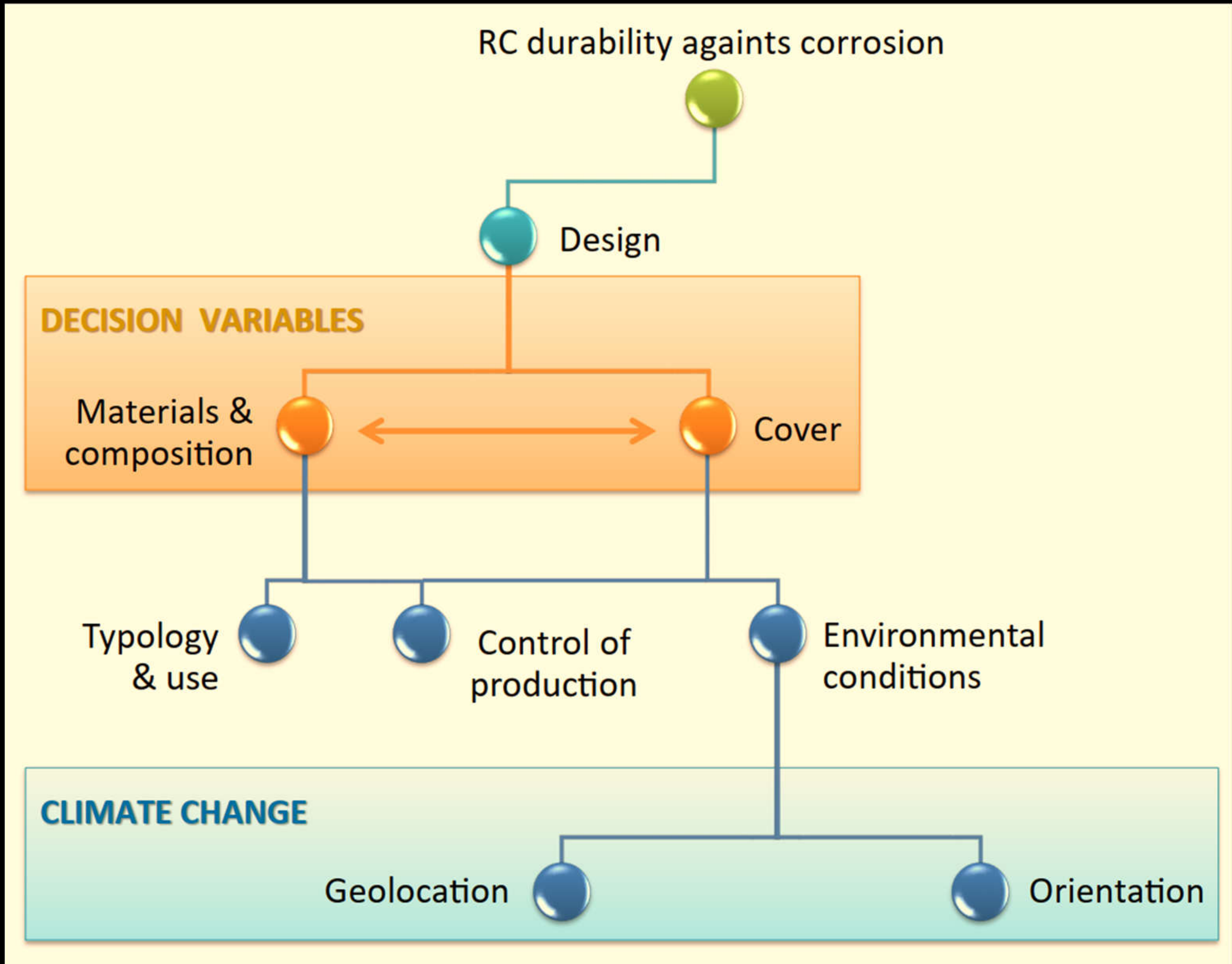
Design phase

- ❑ Increase cover depth
- ❑ Vary concrete composition
  - ✓ Improve concrete grade
  - ✓ Reducing w/c ratio
- ❑ Use new materials
  - ✓ Blended and alkali-activated (AA) cements
  - ✓ Low carbon, stainless or galvanized steel reinforcement, glass-fiber-reinforced polymer rebars

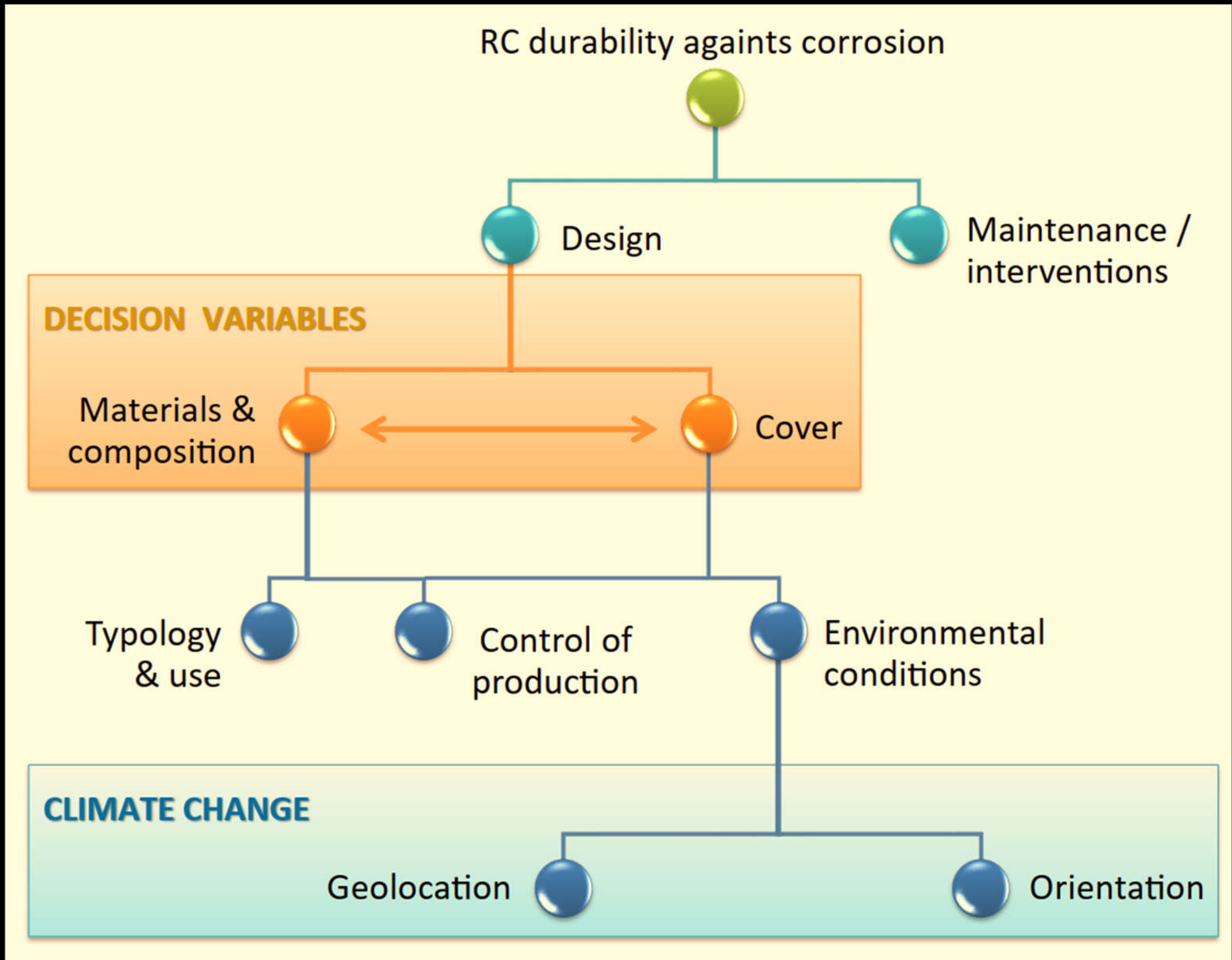
+10 mm
or
+ grade

1-3% of construction costs

RC durability against corrosion



RC durability against corrosion



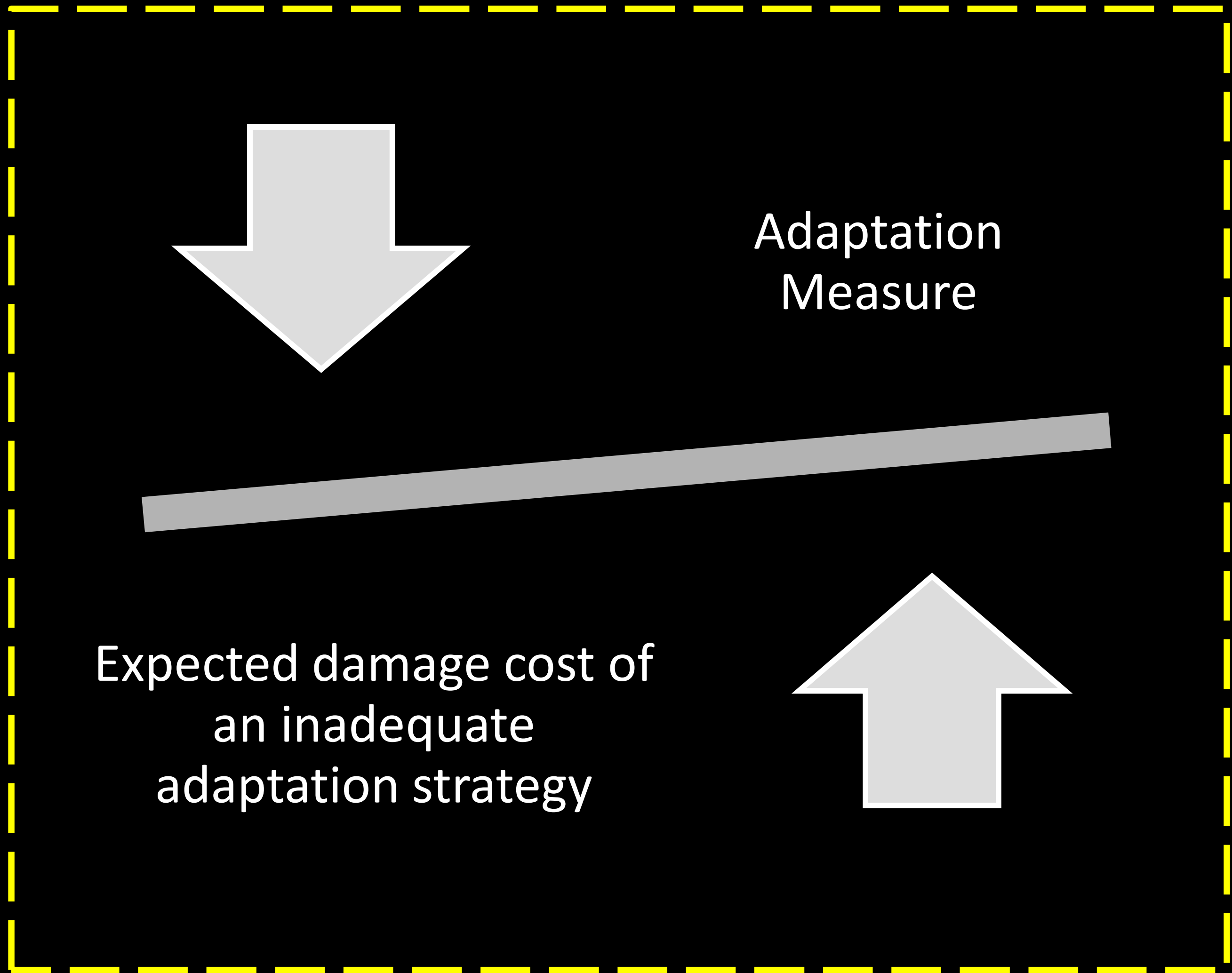
Adaptation measures
Service Life

- ❑ Prevent corrosion
  - ✓ Coating and penetrating sealants — EVERY 10-15 YEARS
- ❑ Rehabilitation of RC
  - ✓ Patch repair — No long-term rehabilitation for chloride
  - ✓ Re-alkalization
  - ✓ Electrochemical chloride extraction — EVERY 15-20 YEARS*

Climate change vulnerability & adaptation

Viability of solutions

Cost-Benefit Analysis



Uncertainty of Climate Change

Viability of solutions

Cost-Benefit Analysis

Mean Benefit-Cost Ratio (*Pr[BCR>1])* for CC over 100 years. Marine environment

Slabs (De=300mm)

	5 mm Increase in Design Cover								10 mm Increase in Design Cover							
ΔRH	$\Delta T = 0°C$		$\Delta T = 2°C$		$\Delta T = 4°C$		$\Delta T = 6°C$		$\Delta T = 0°C$		$\Delta T = 2°C$		$\Delta T = 4°C$		$\Delta T = 6°C$	
−10%	0.33	*(8%)*	0.53	*(8%)*	0.57	*(9%)*	0.57	*(9%)*	0.29	*(8%)*	0.39	*(8%)*	0.39	*(9%)*	0.40	*(9%)*
0%	0.68	*(18%)*	0.91	*(20%)*	0.94	*(22%)*	0.95	*(23%)*	0.60	*(18%)*	0.67	*(20%)*	0.69	*(22%)*	0.78	*(23%)*
10%	1.17	*(34%)*	1.27	*(37%)*	1.35	*(38%)*	1.32	*(40%)*	0.92	*(34%)*	1.03	*(37%)*	1.07	*(38%)*	1.07	*(40%)*
20%	1.65	*(50%)*	1.70	*(53%)*	1.72	*(55%)*	1.76	*(59%)*	1.36	*(50%)*	1.42	*(54%)*	1.45	*(56%)*	1.47	*(59%)*

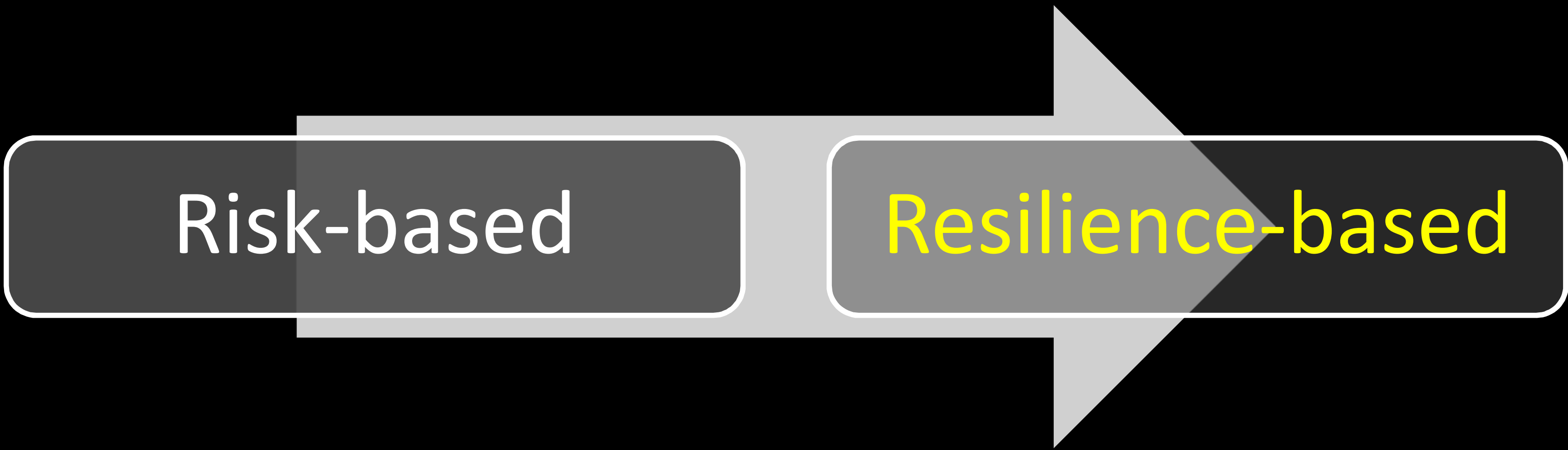
Columns (De=300mm)

	5 mm Increase in Design Cover								10 mm Increase in Design Cover							
ΔRH	$\Delta T = 0°C$		$\Delta T = 2°C$		$\Delta T = 4°C$		$\Delta T = 6°C$		$\Delta T = 0°C$		$\Delta T = 2°C$		$\Delta T = 4°C$		$\Delta T = 6°C$	
−10%	0.10	*(5%)*	0.16	*(7%)*	0.18	*(8%)*	0.19	*(8%)*	0.09	*(4%)*	0.12	*(4%)*	0.12	*(5%)*	0.13	*(5%)*
0%	0.21	*(7%)*	0.29	*(8%)*	0.30	*(9%)*	0.31	*(11%)*	0.19	*(5%)*	0.21	*(5%)*	0.21	*(6%)*	0.24	*(6%)*
10%	0.36	*(9%)*	0.40	*(11%)*	0.42	*(12%)*	0.41	*(12%)*	0.29	*(5%)*	0.32	*(6%)*	0.34	*(7%)*	0.34	*(7%)*
20%	0.45	*(13%)*	0.50	*(13%)*	0.52	*(14%)*	0.55	*(14%)*	0.43	*(7%)*	0.45	*(8%)*	0.44	*(9%)*	0.46	*(9%)*

Stewart & Bastidas-Arteaga (2019). Corrosion of Concrete and Steel Structures in a Changing Climate. In Climate Adaptation Engineering (pp 99-125). Butterworth-Heinemann

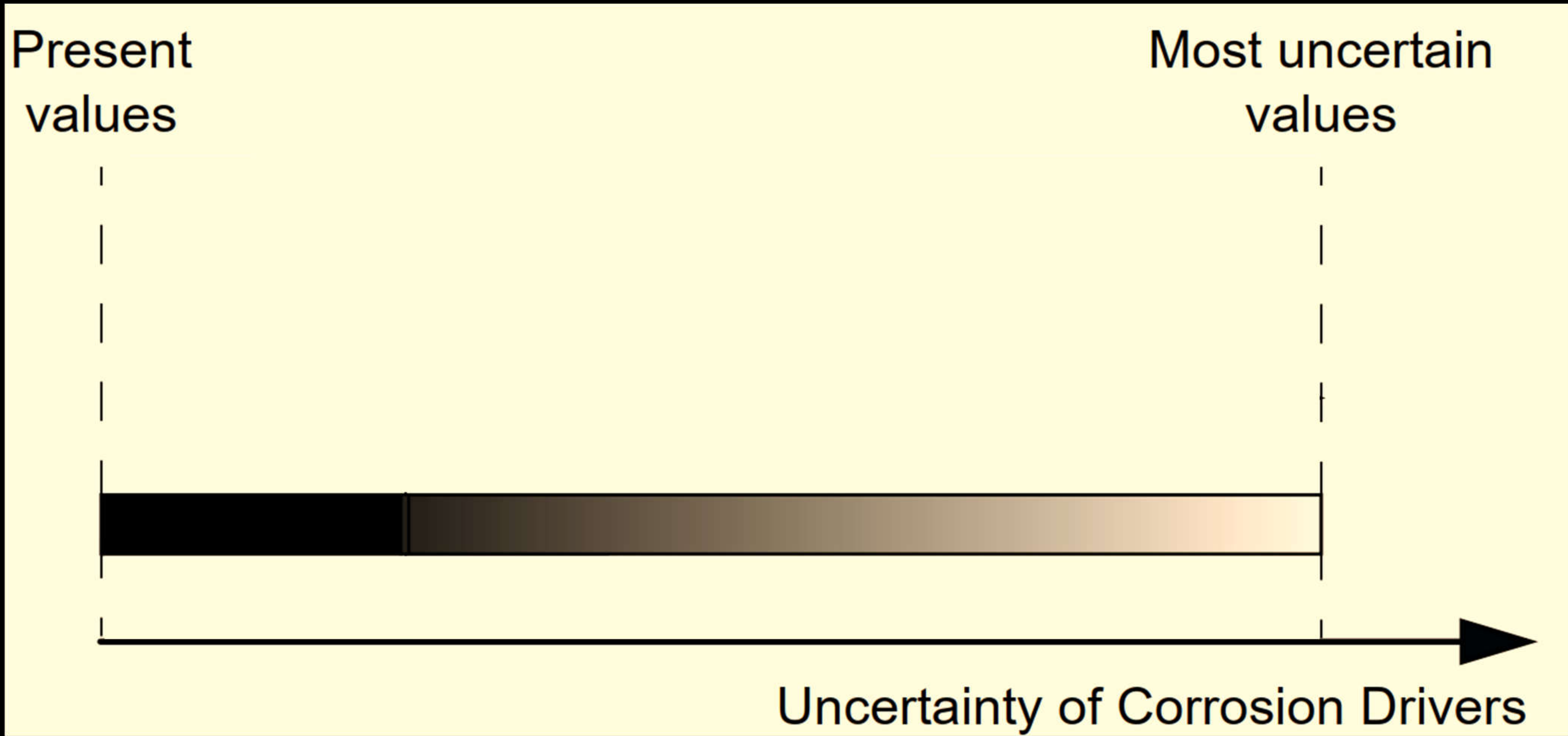
A resilience-based approach for adaptation

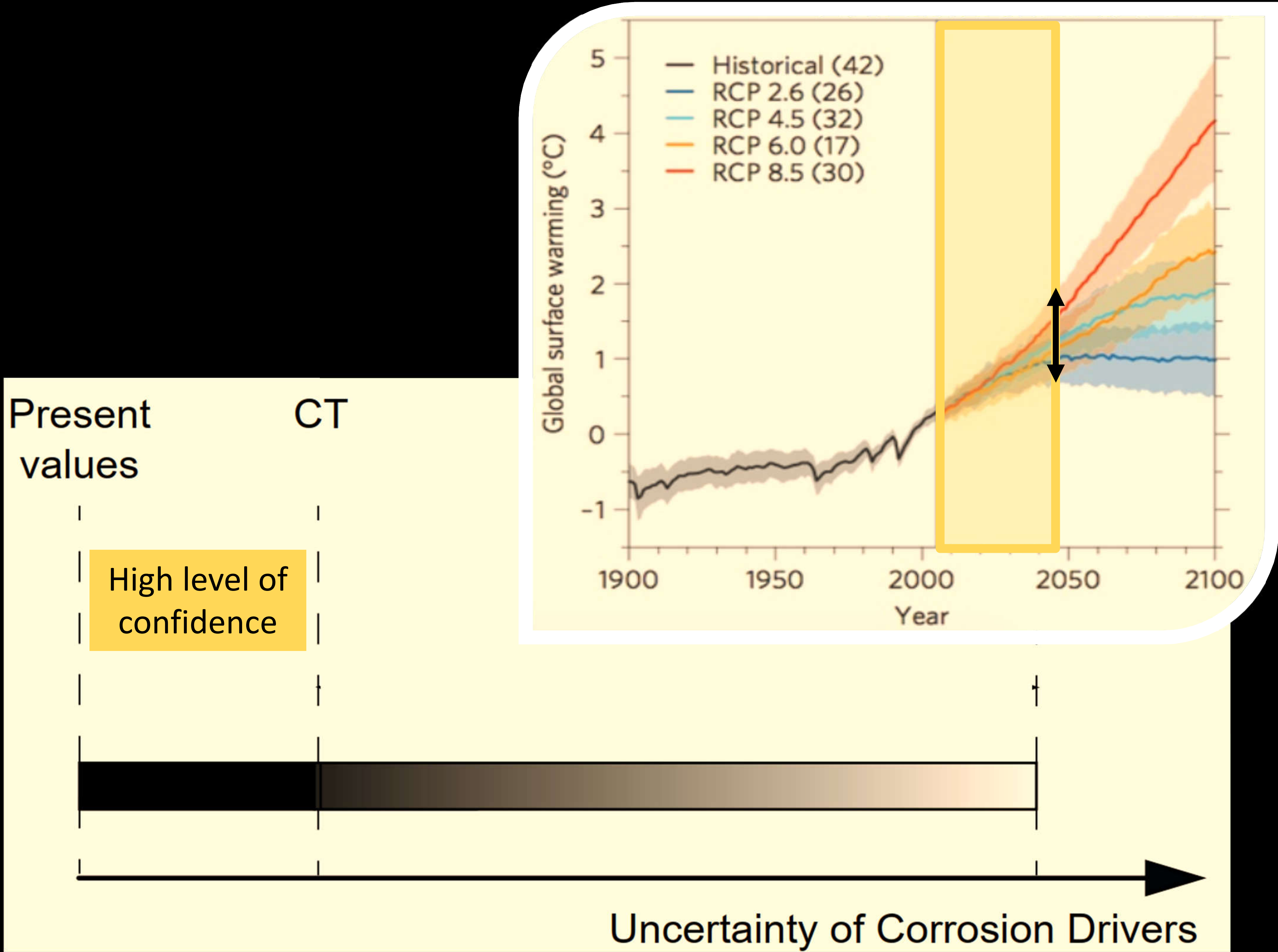
Risk-based vs Resilience



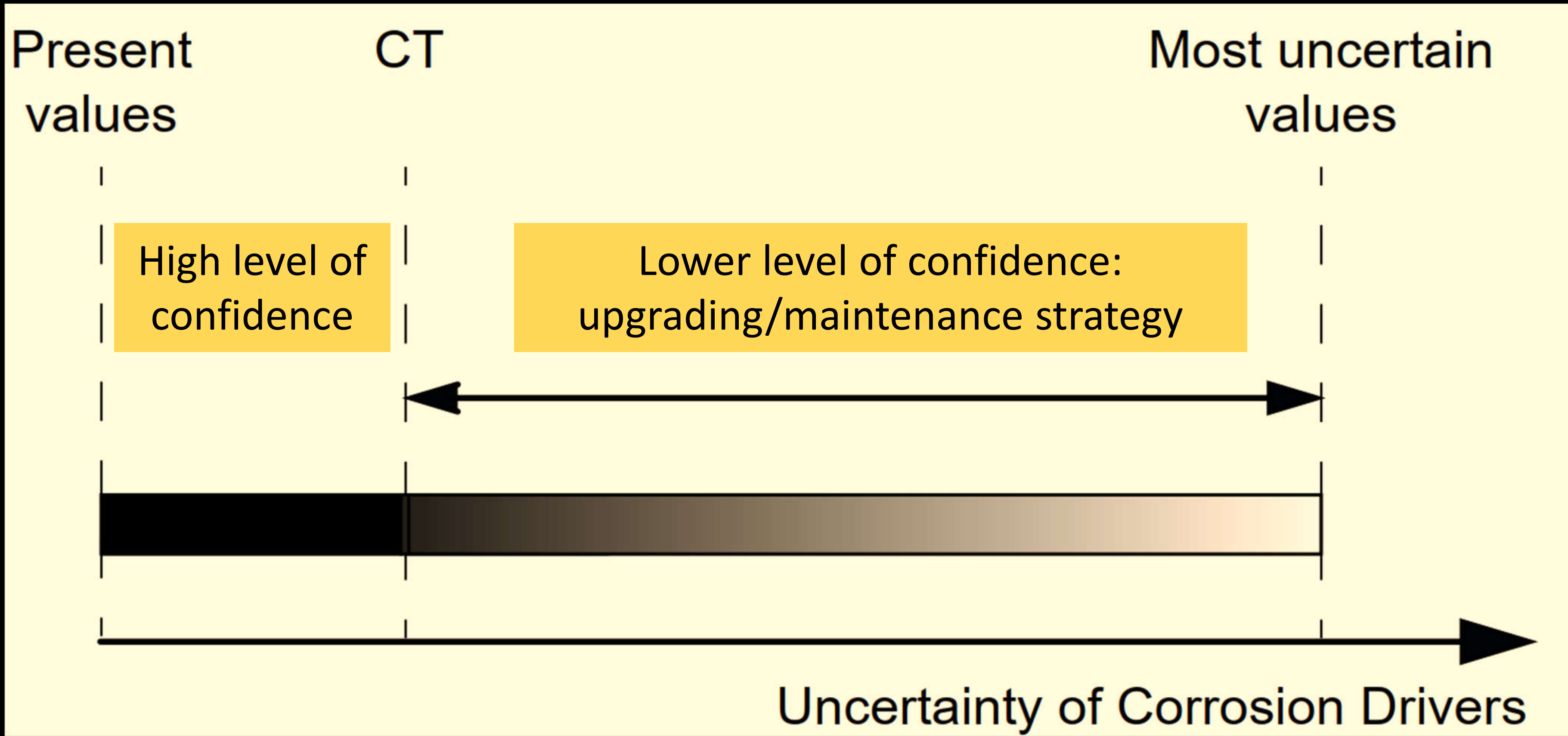
Lack of knowledge
Temporal dimension
Strategies to increase preparedness
Adaptive response over time

Resilience-based framework




Present values
CT
High level of confidence
Uncertainty of Corrosion Drivers
Historical (42)
RCP 2.6 (26)
RCP 4.5 (32)
RCP 6.0 (17)
RCP 8.5 (30)
Global surface warming (°C)
Year
1900
1950
2000
2050
2100
5
4
3
2
1
0
-1

Resilience-based framework

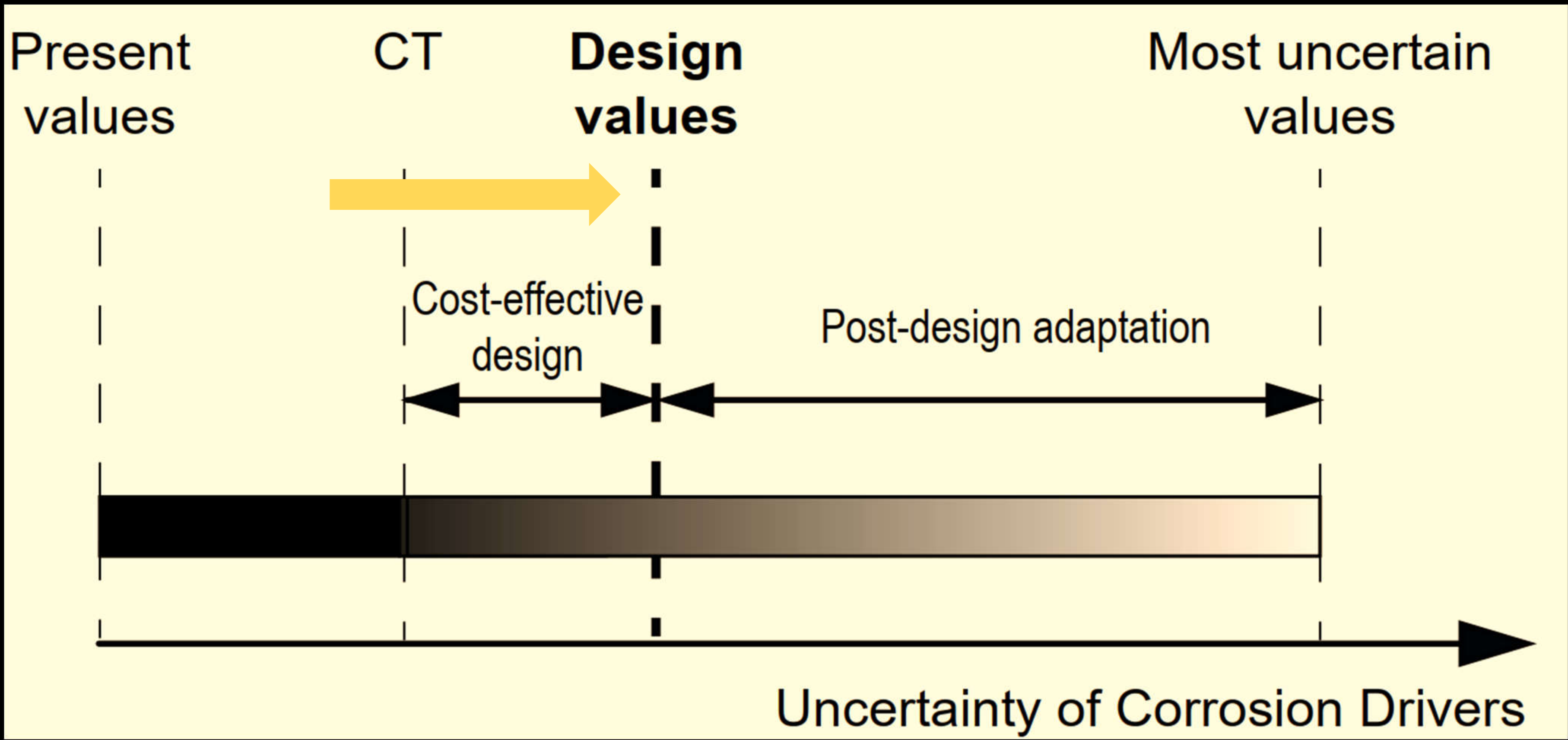


Maintenance plan *in the design stage*

For several scenarios, a detailed maintenance plan

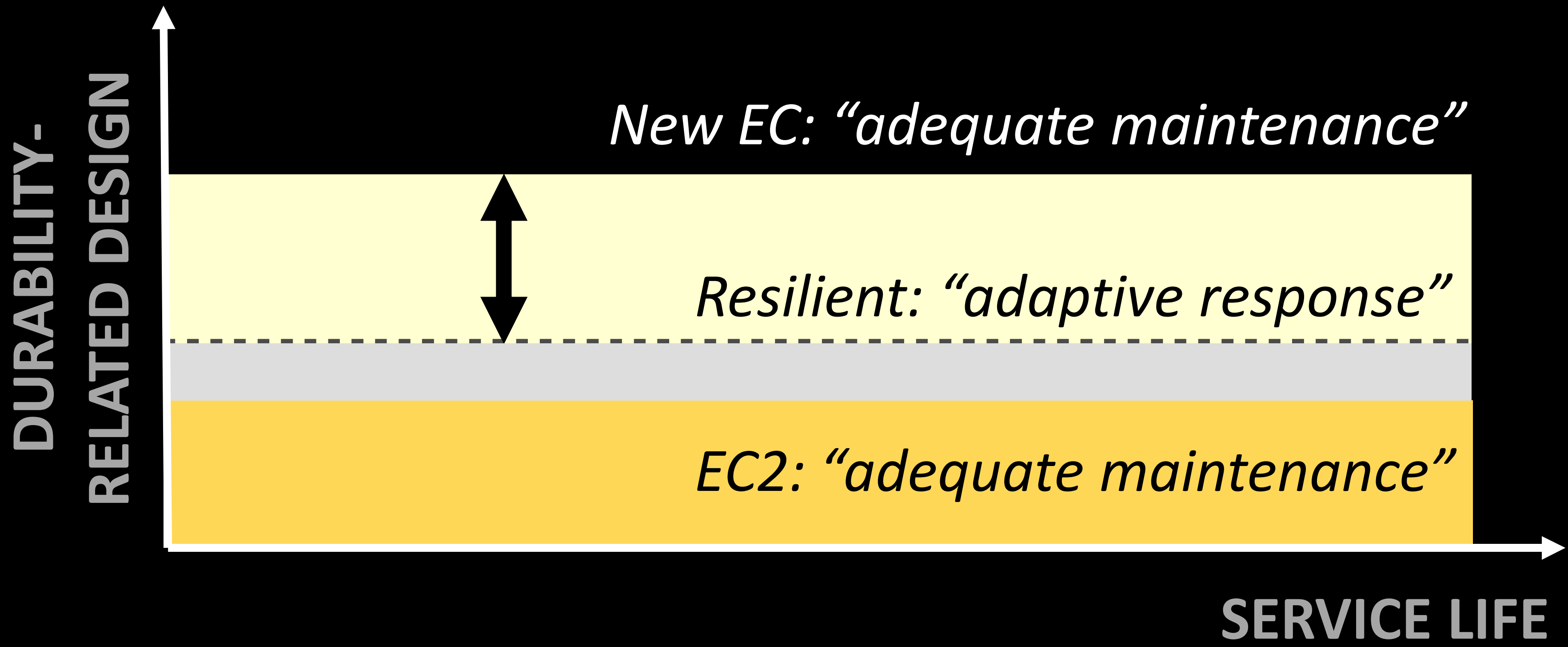
- ❑ Type of maintenance (preventive, predictive, corrective)
- ❑ Detailed actions, adapting the structural design
- ❑ Economical viability study

Resilience-based framework



Closure. Challenges and opportunities

- ✓ Main challenge: uncertainty of climate change
- ✓ “Win-win, low-cost and no-regret” adaptation measures



Climate Adaptation within the European roadmap

Action and the possible impact on cement-related CO_2
(% reduction in emissions)

Carbon capture and storage	95-100%
Novel cements	90-100%
Clinker substitution	70-90%
Alternative fuels	40%
Energy efficiency	4-8%

Source: Chatham House

THANKS FOR YOUR ATTENTION

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