Resilience of critical infrastructures in Europe to climate change

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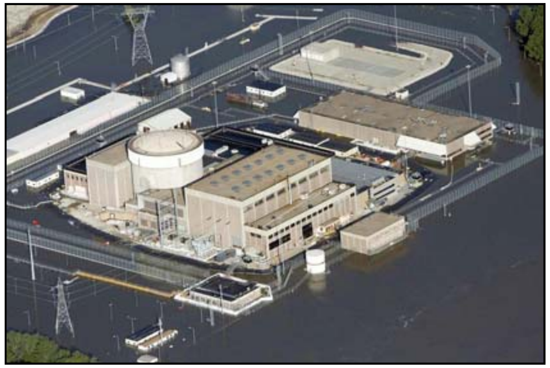


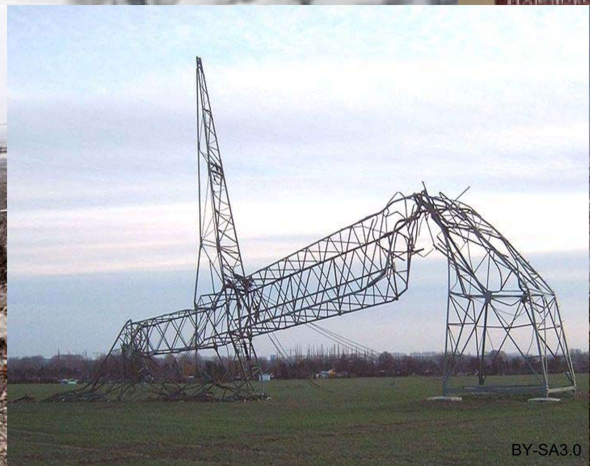
ECONADAPT

Policy workshop

Brussels, 27 September 2016

National Geographic

Travel



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Dalje

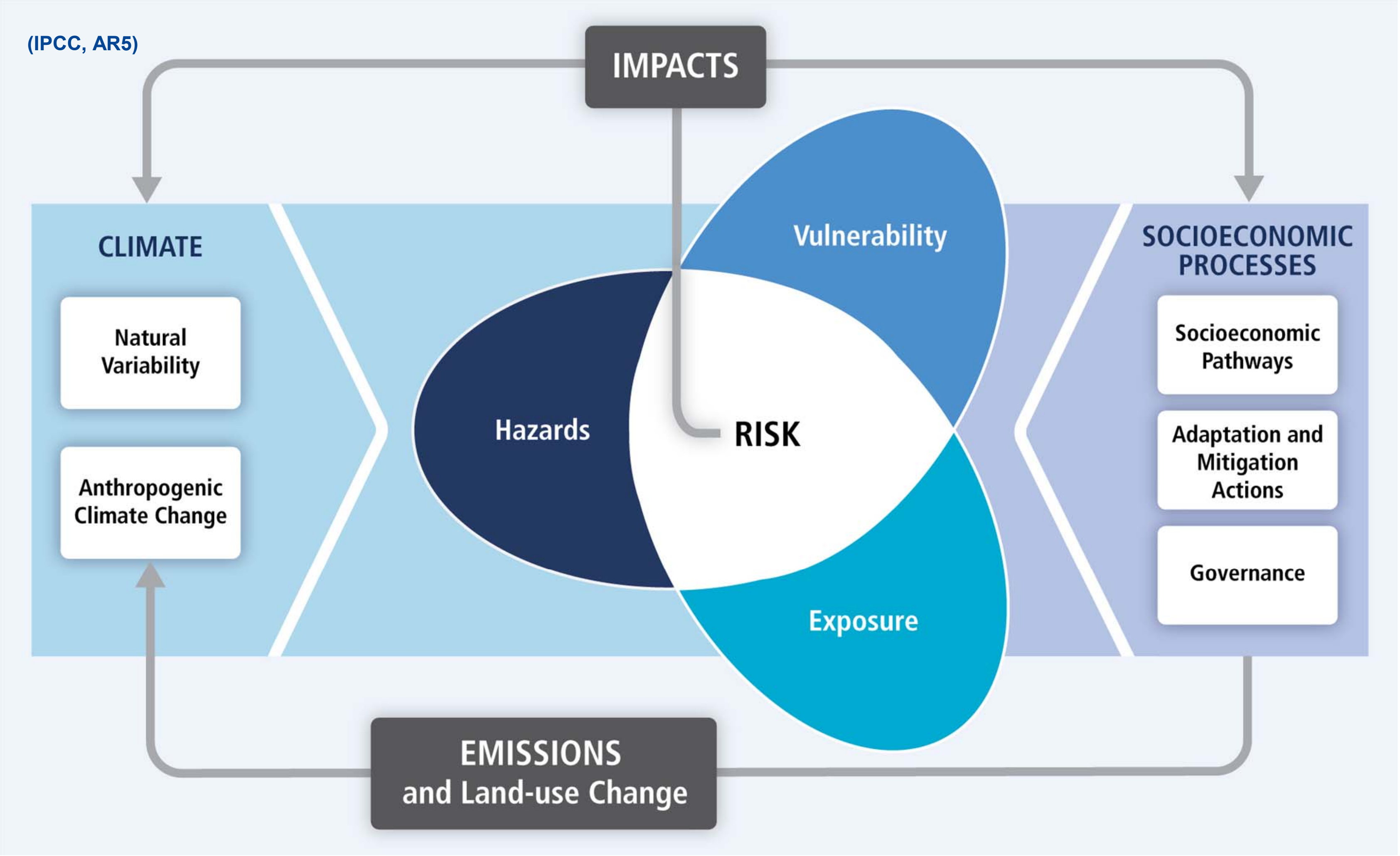
CCMFF overall goals

- **Main objective**
  - "evaluate current and future impacts of climate variability and climate change (**CC**) on critical infrastructures and EU funded projects within the current and future Multiannual Financial Frameworks (**MFF**)"

- **Support to policy**
  - EU Adaptation Strategy
    - informed decision-making - addressing existing gaps
    - 2017 Adaptation Strategy review

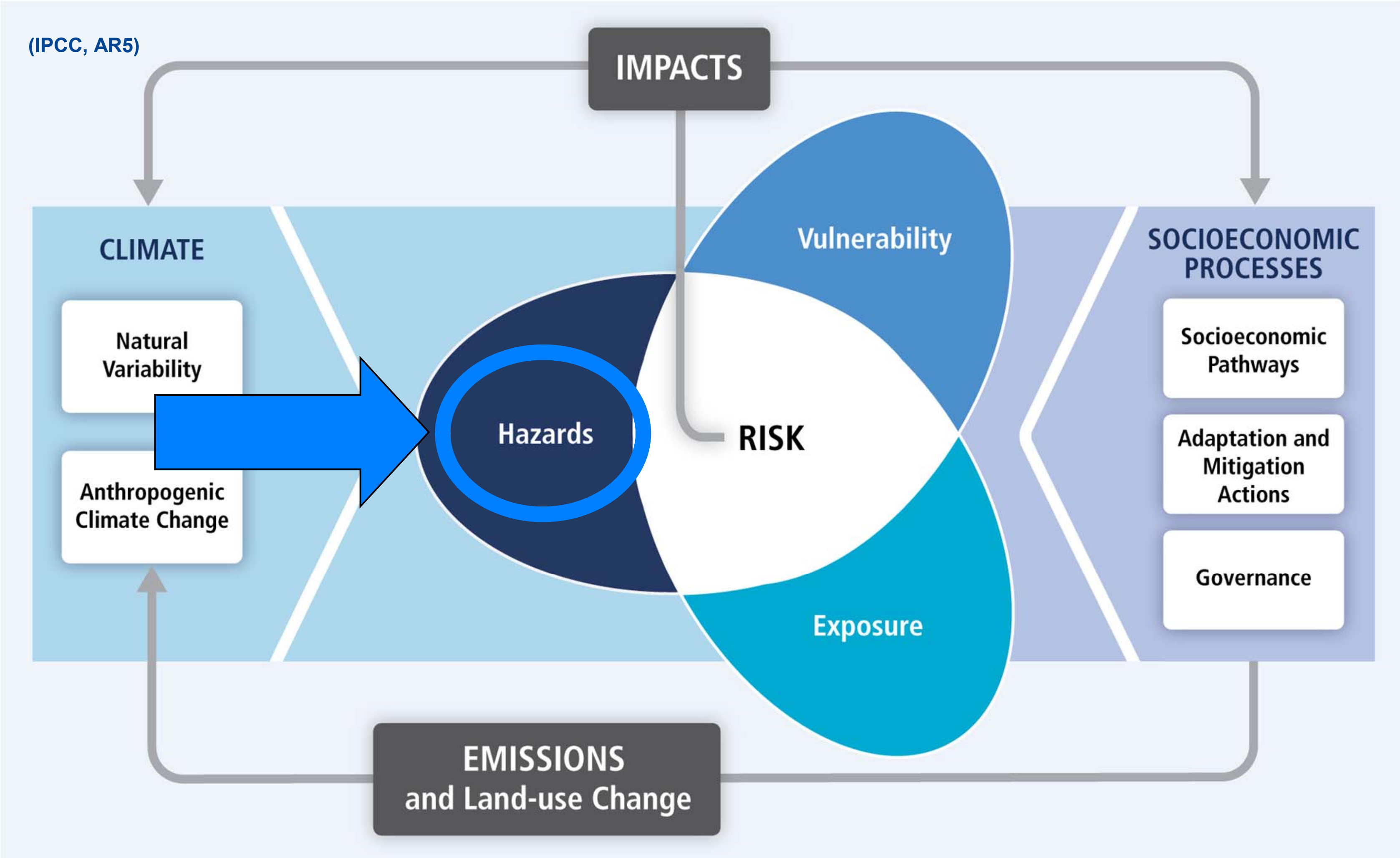
- **Scientific challenge**
  - First multi-hazard multi-sector risk assessment for critical infrastructural assets under climate change

Methodological framework

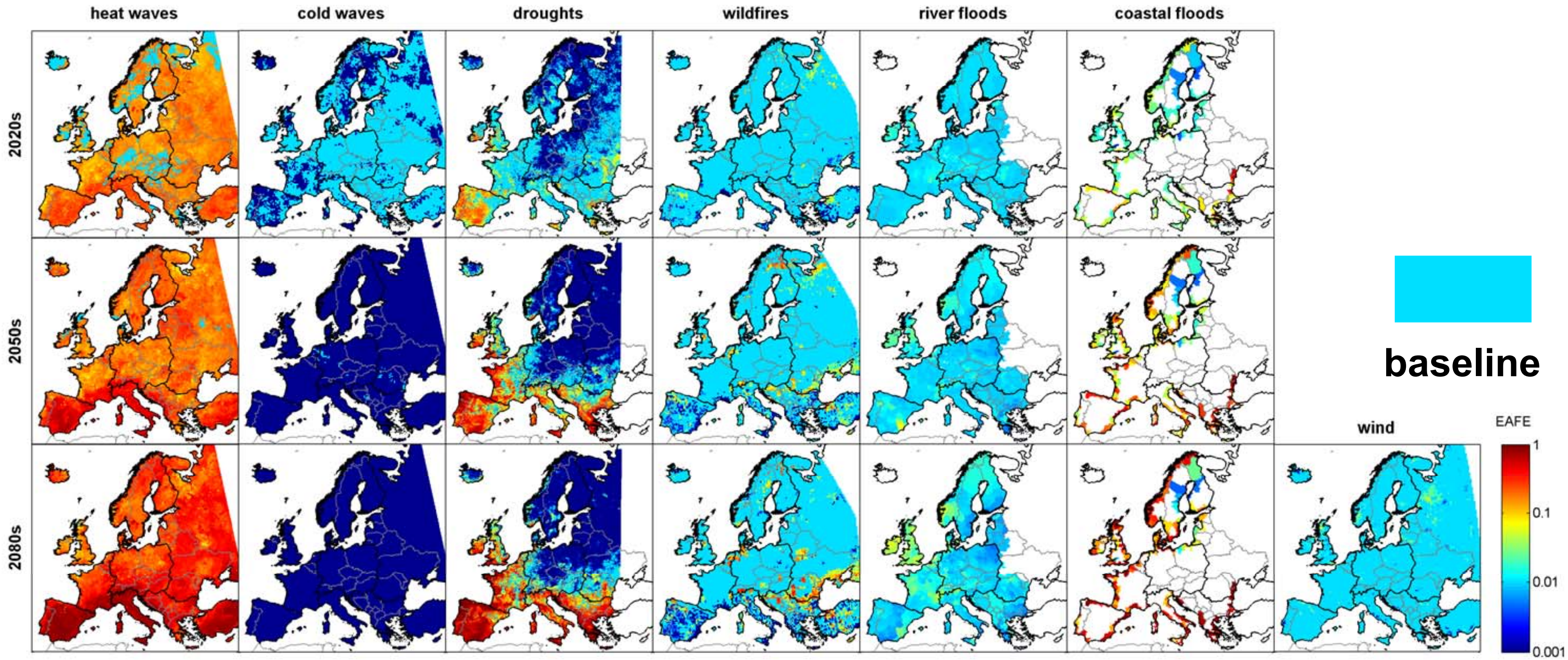


Methodological framework

Challenge 1: Climate hazards

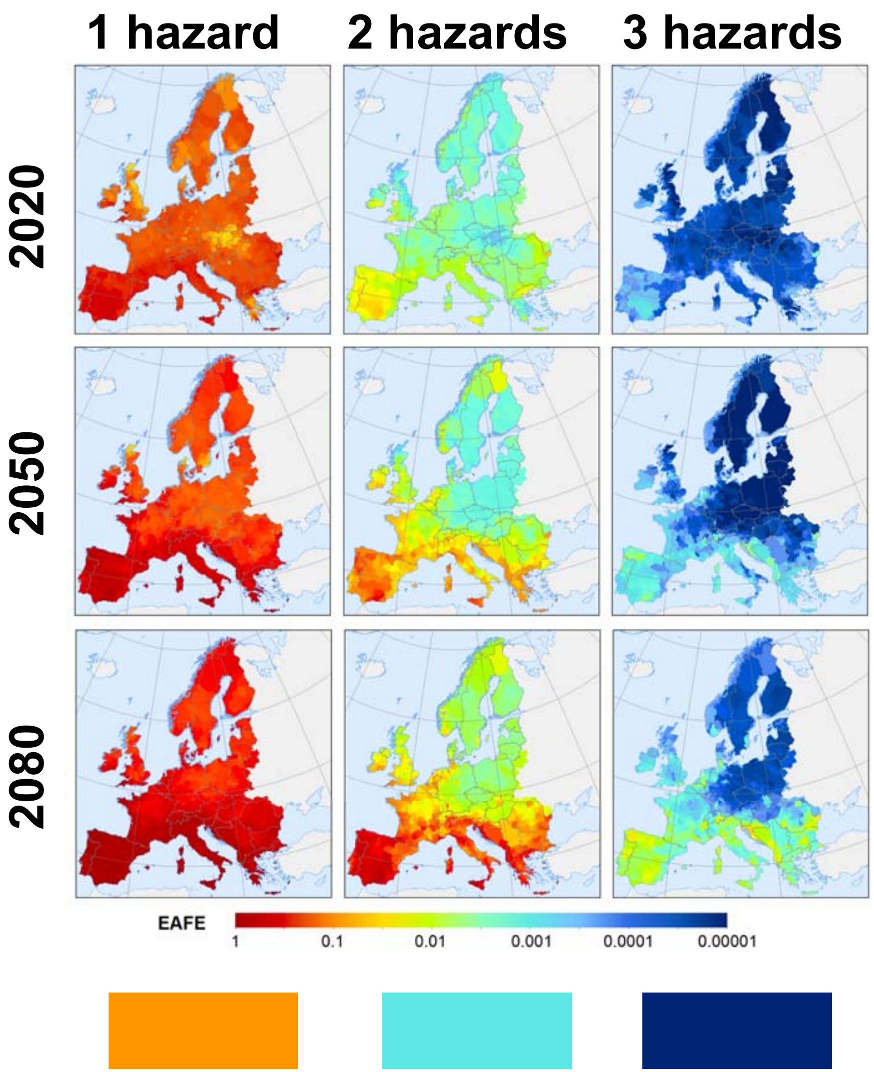


Changes in climate hazards



Expected Annual Fraction Exposed to a current 100-year event

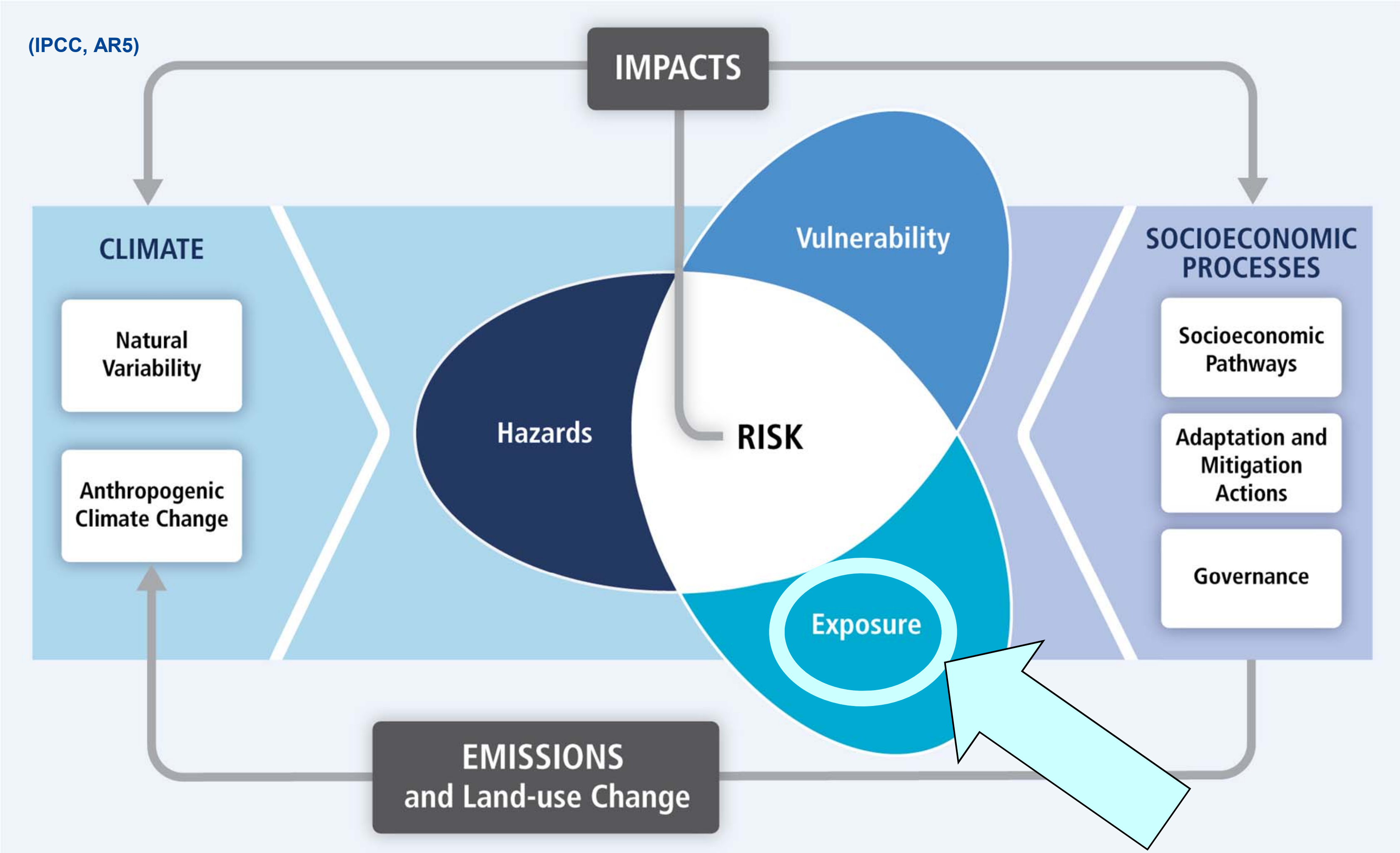
Changes in multiple climate hazards



Evolution in time and space of the fraction of a unit **area that is expected to be exposed annually (EAFE) to at least one (left), two (middle) and three (right) hazards with a current 100-year intensity**.

At present, approximately 0.05, 0.001, and 10^{-5} % of the area in Europe is expected to be annually exposed to at least one, two and three hazards of this intensity, respectively.

Challenge 2: Mapping of assets



Challenge 2: Mapping of assets

- **Critical infrastructures**: essential for the maintenance of vital societal functions, health, safety, security, economic, or social well-being of people (Directive 2008/114/EC).
- **Spatial coverage:** EU28 + EFTA
- **Multiple geographical data sources:** proprietary and open source

Critical infrastructures (CI)

Transport
- Roads
- Railways
- Inland waterways
- Ports
- Airports

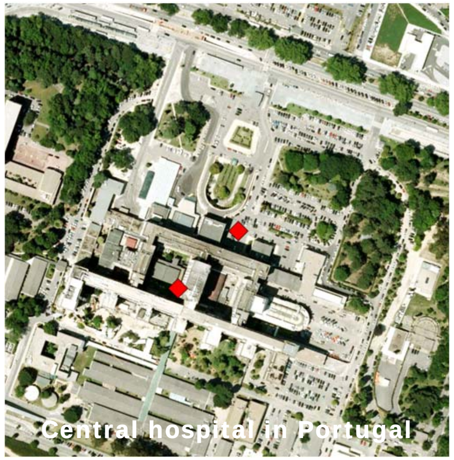
Industry
- Metals
- Minerals
- Extraction sites
- Refineries
- Chemical
- Water and waste treatment

Social
- Education
- Health

Energy
- Non-renewable power plants
  - Coal
  - Gas
  - Nuclear
  - Oil
- Renewable power plants
  - Biomass
  - Hydro
  - Solar
  - Wind
- Energy transport
  - Electricity distribution/transmission
  - Gas pipelines

CI – data collection and preparation


Port in Estonia

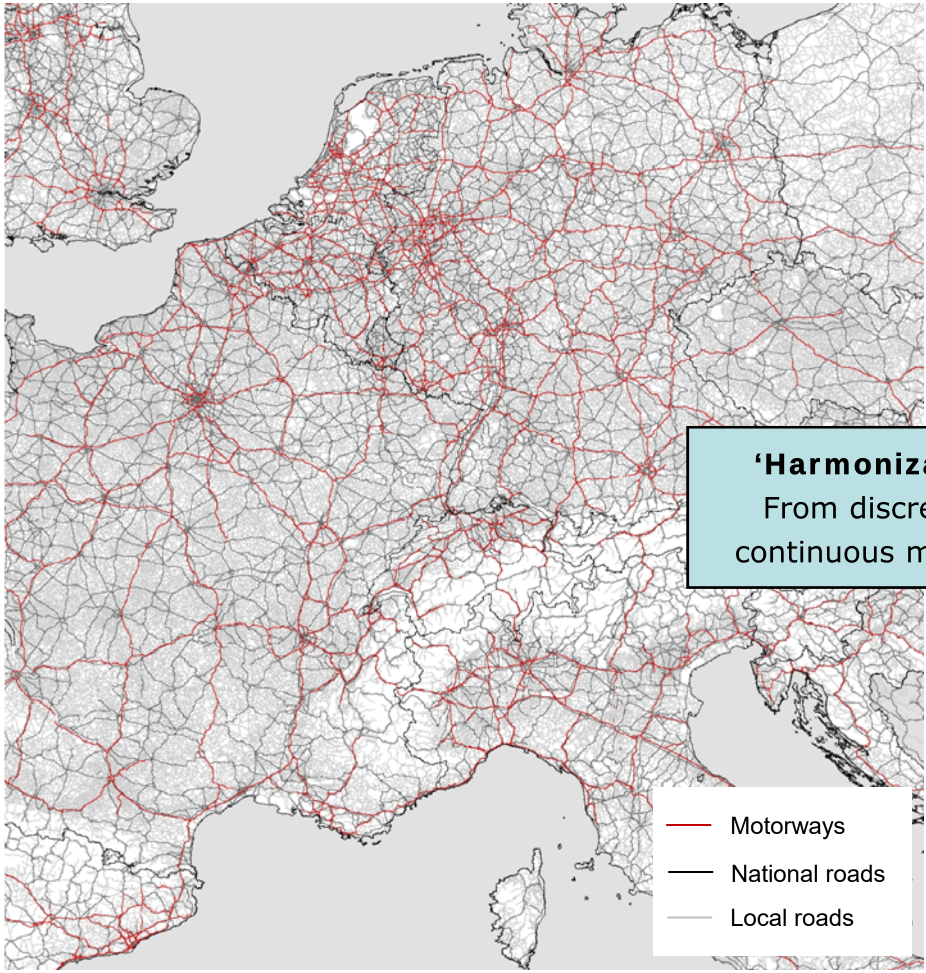

Central hospital in Portugal


Airport in Belgium


Nuclear power plant in Spain

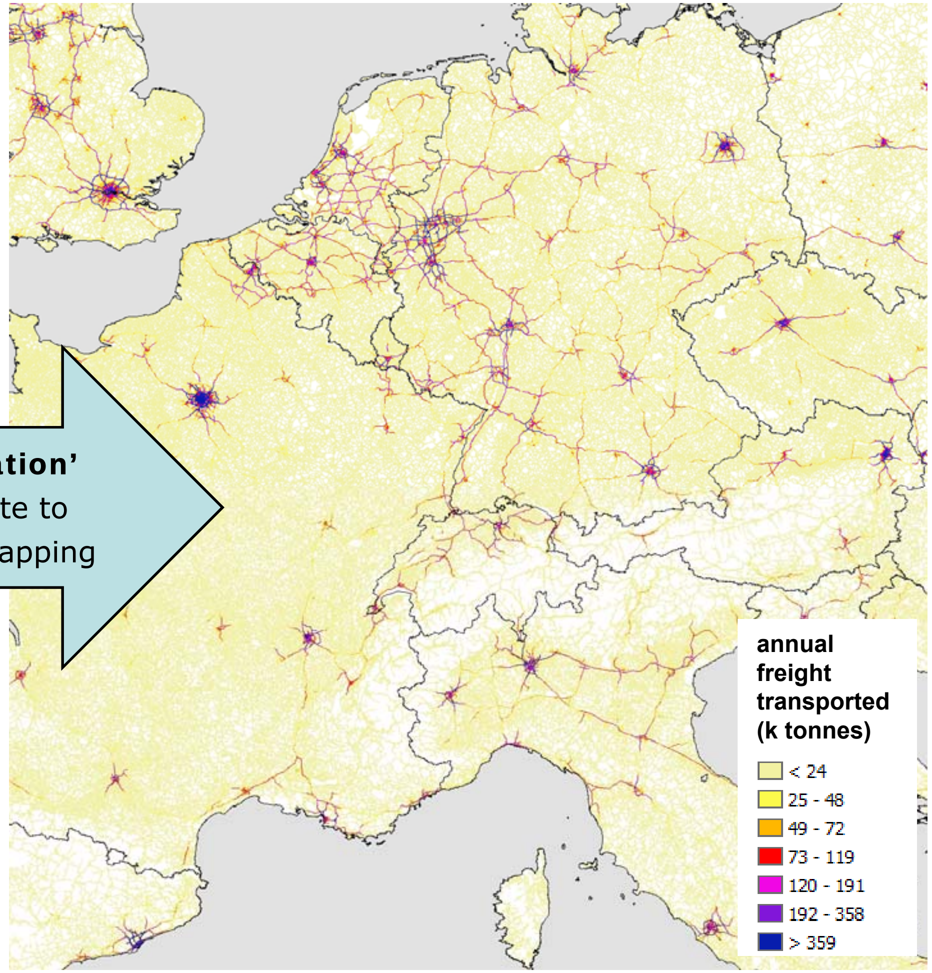
CI – data harmonization

Roads described by category

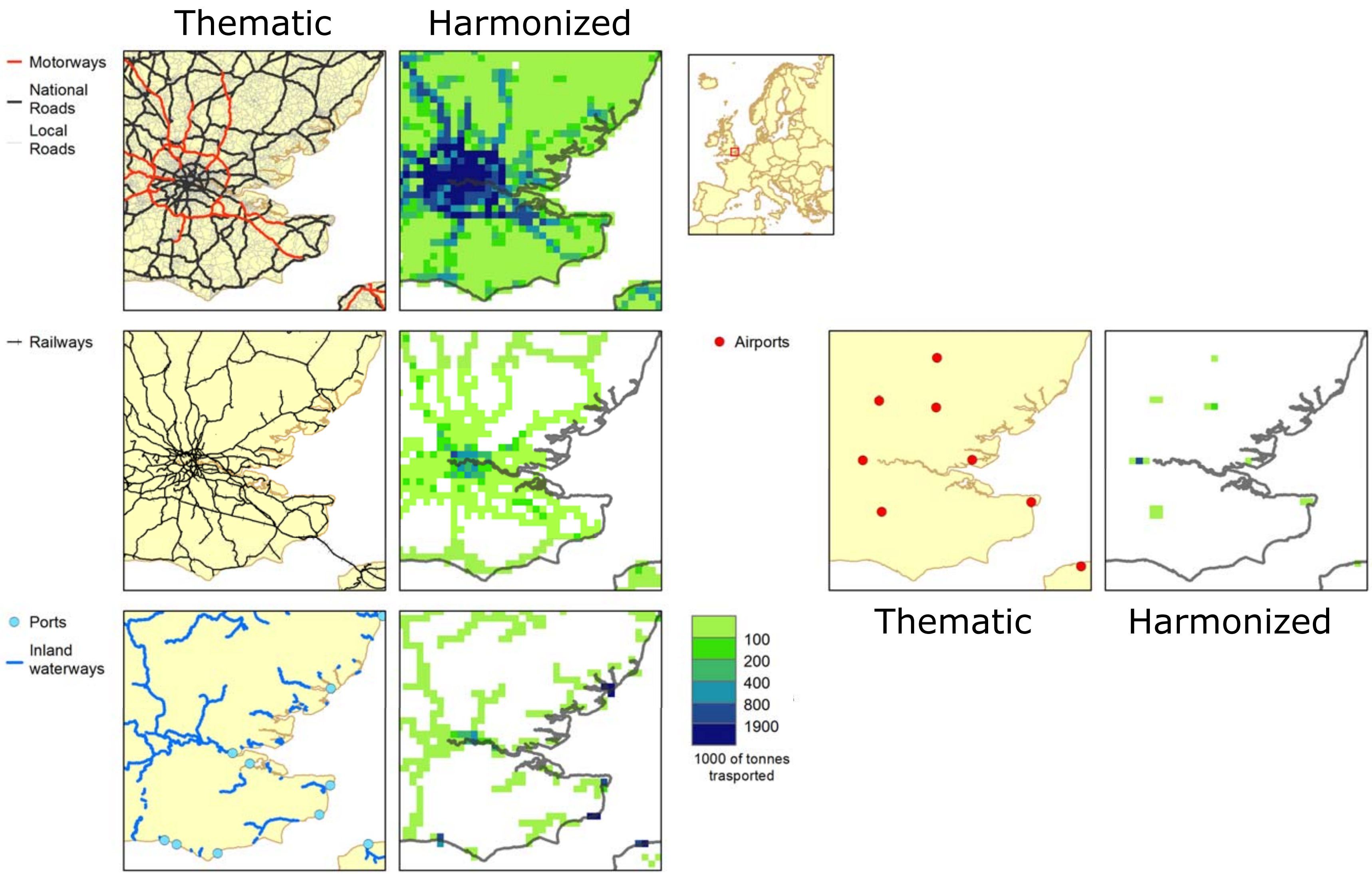


'Harmonization'
From discrete to continuous mapping

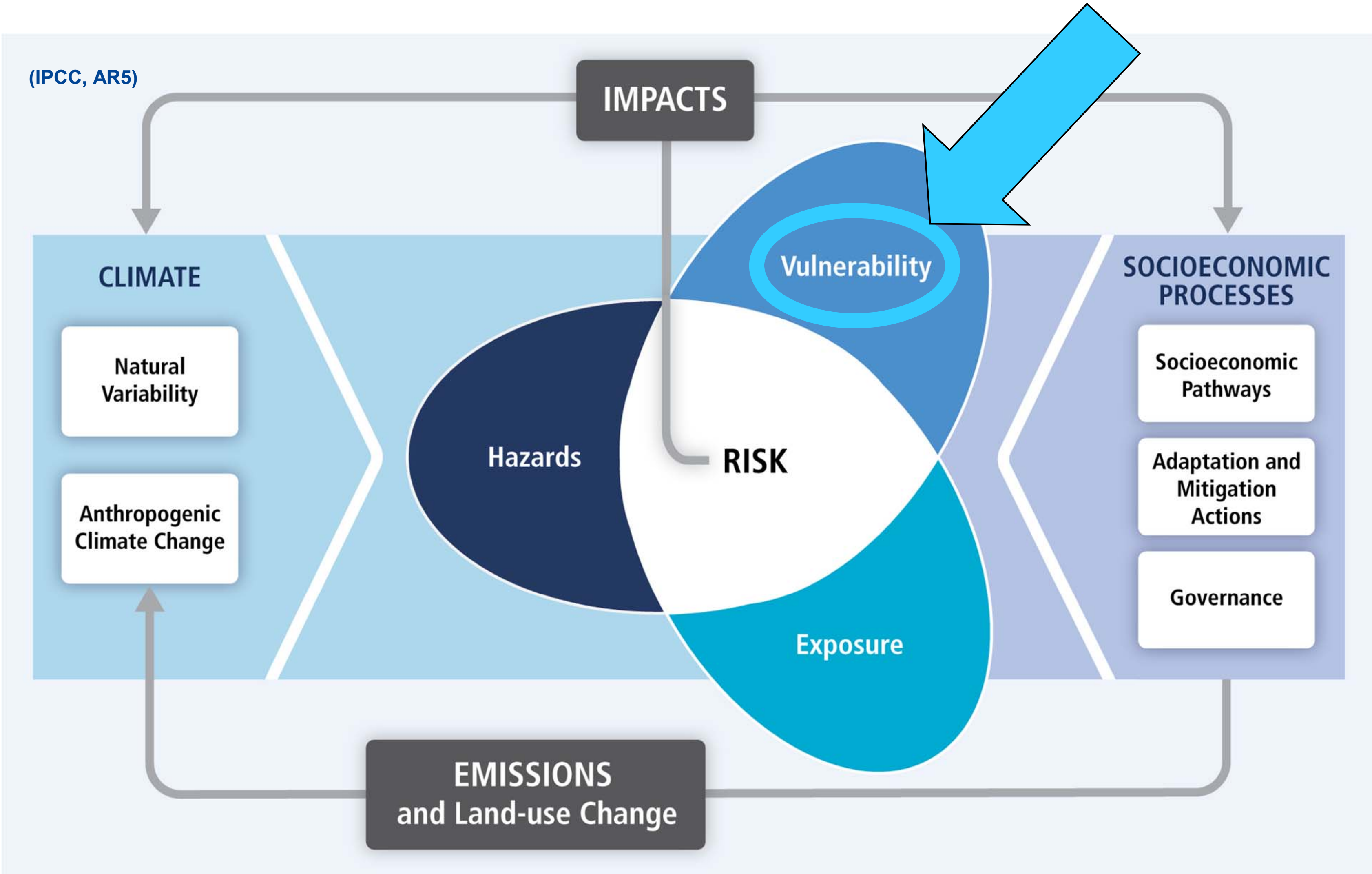
Roads described by intensity



Exposure – harmonized transport layers



Challenge 3: Vulnerability



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Vulnerability – literature review

	Heat waves	Cold	Droughts	Wildfires	River and coastal floods	Windstorms
Energy	Structural damages due to expansion of different materials. Reduction of structural integrity due to melting permafrost. Increased resistance on the power lines. Decrease in power plant efficiency due to higher water temperature required for cooling systems.	Structural damages due to increased ice and snow loads overhead distribution lines and ice-induced changes in pipeline pressures. Increased corrosion on energy systems. Reduction in hydropower potential due to water freezing. Reduction in biofuels sources.	Reduction of structural integrity due to melting of permafrost and drought-induced subsidence. Deterioration of power systems caused by overexploitation of irrigation and water pumping. Decrease in power plant efficiency due to higher water temperature and lower water volumes required for cooling systems. Deterioration of cooling systems due to excessive biological growth and clog water intakes. Reduction in biofuels sources.	Damages to power systems equipment. Reduction in biofuels sources. Damage to pipelines and electricity. transmission lines from bushfires.	Structural damages to energy production sites transport networks due to direct impacts of overflows, reduced soil stability and induced mass movements (soil erosion, landslide, siltation). Damages to power systems equipment due to debris and pollution in cooling water flows required. Short-circuiting and power failure on electrical systems. Disabled corrosion protection equipment and produce pitting. Reduction in	Structural damages to power systems equipment and storage tanks due to wind pressure or debris impact. Overloads of tidal and wave energy plants. Disruption of electricity lines (transmission and distribution networks) and damages to cables due to falling trees. Short-circuiting triggering possible fires especially with storage of liquid flammable hydrocarbons.

Vulnerability – expert survey

- **Expert survey**
  - **50 themes for SCF/CI sectors**
  - **~ 500 experts for each sector**
    - academics + field experts
    - editorial boards
    - sector specific
    - climate impact experts
  - **~ 10% responses**
    - 40-50 answers/sector
  - **Anonymous**
  - **Use of commission survey tool**
    - http://ec.europa.eu/eusurvey

Climate Sensitivity of Transport Infrastructures and Investments

Here, sensitivity refers to what degree the asset or system is affected when exposed to a climate hazard.

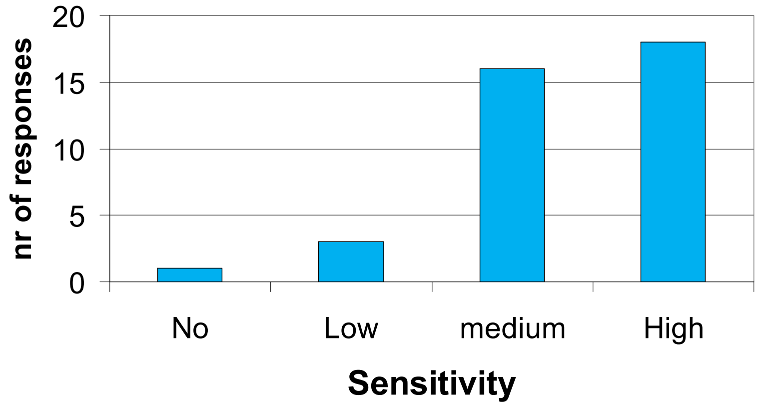
Sea level rise / storm surges

How sensitive are the following infrastructures/ investments to **sea level rise / storm surges** ?

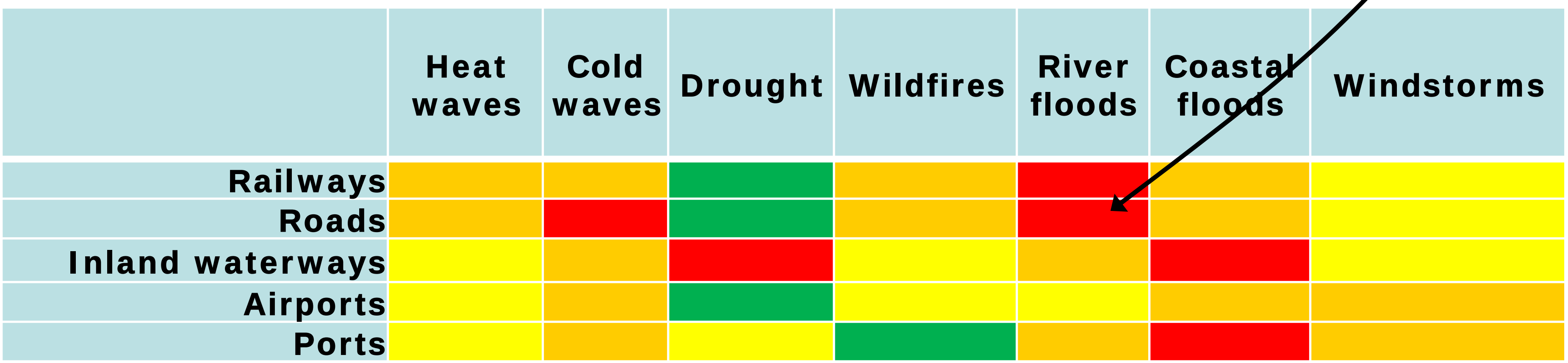
	No	Low	Medium	High
Railways				
Mobile rail assets				
Motorways				
National roads				
Regional/local roads				
Urban transport				
Cycle tracks				
Multimodal transport				
Intelligent transport systems				
Airports				
Ports				
Inland waterways				

Vulnerability – expert survey

Sensitivity of roads to river floods



mode distribution



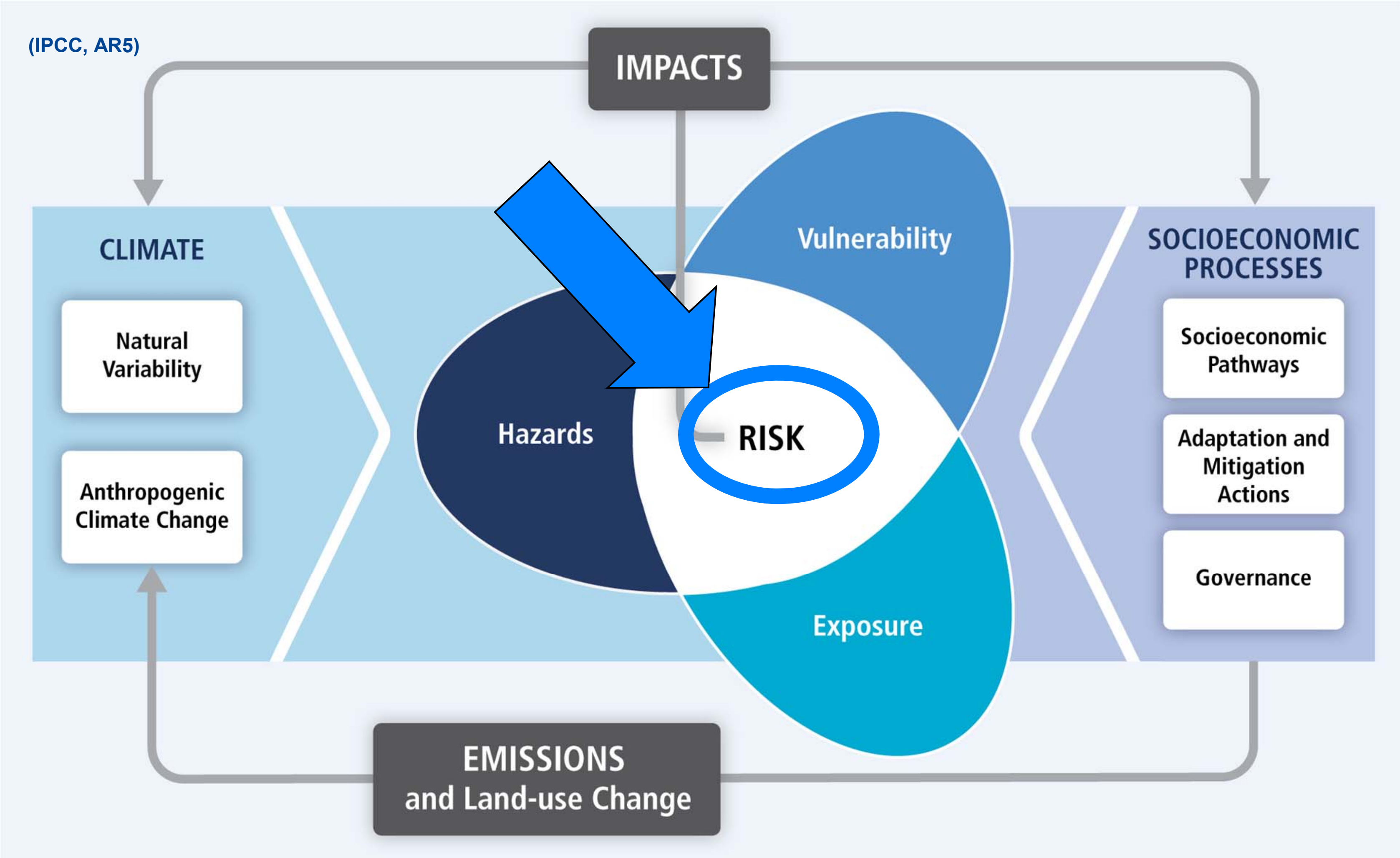
Vulnerability – sensitivity matrix CI

ENERGY	drought	flood	SLR	fire	cold	heat	wind
Nuclear power plants							
Coal fired power plants							
Gas fired power plants							
Oil fired power plants							
Electricity transmission/distribution							
Gas pipelines							
Wind							
Solar							
Biomass							
Hydro							
TRANSPORT	drought	flood	SLR	fire	cold	heat	wind
Rails							
Roads							
Airports							
Ports							
Inland Waterways							
INDUSTRY	drought	flood	SLR	fire	cold	heat	wind
Metals							
Chemical							
Refineries							
Minerals							
Water/waste management							
SOCIAL	drought	flood	SLR	fire	cold	heat	wind
Education							
Health							

No sensitivity
Low sensitivity
Medium sensitivity
High sensitivity

Sensitivity of critical infrastructures based on expert survey and literature

Challenge 4: Risk



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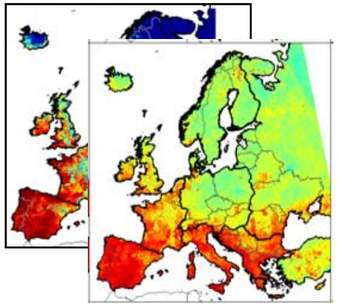
Risk quantification

Climate hazards



The fraction of an area expected to be annually exposed to different intensities of a specific hazard

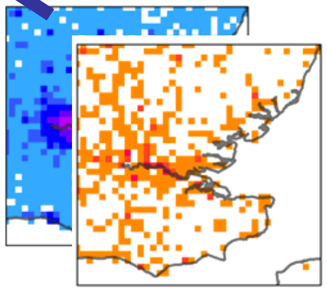
Risk matrix

HAZARD			SENSITIVITY No	Low	Med	High
	rp > 100 yr	Very high (VH)	N	M	H	VH
	50 yr < rp <100 yr	High (VH)	N	M	M	H
	20 yr < rp < 50 yr	Moderate (M)	N	L	M	M
	10 yr < rp <20 yr	Low (L)	N	L	L	M
	2yr < rp <10 yr	Very Low (VL)	N	VL	L	L
	rp < 2 yr	No (N)	N	N	N	N

RISK LEVEL

VH	Very High
H	High
M	Medium
L	Low
VL	Very Low
N	No

Harmonized exposures



The amount of assets in an area expressed in harmonized intensity

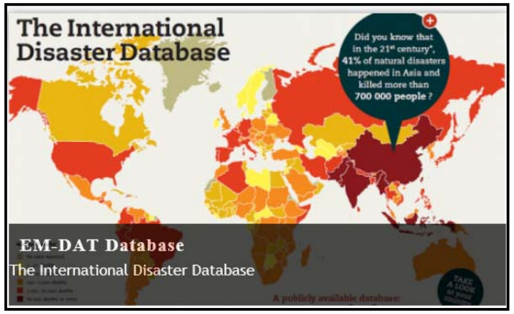
amount of assets under different risk levels for each of the 7 hazards

Example:

In region Y, 1% of energy assets or 2.1^4 toe annually under high risk from drought in baseline

In region Y, 4% of energy assets or 8.4^4 toe annually under high risk from drought by 2050s

Risk quantification



baseline damages per hazard and country

national shares of the monetary value of sector-specific capital stock and gross value added + **sensitivity to hazard**

28% for coastal flooding
90% for cold
45% for drought
14% for fire
28% for flood
67% for heat
21% for windstorms

baseline damages per hazard, sector and country

disaggregated to NUTS2 level based on NUTS2 GDP shares within a country

baseline damages per hazard, sector and NUTS2

Risk quantification

			SENSITIVITY			
			No	Low	Med	High
HAZARD	rp > 100 yr	Very high (VH)	N	M	H	VH
	50 yr < rp <100 yr	High (VH)	N	M	M	H
	20 yr < rp < 50 yr	Moderate (M)	N	L	M	M
	10 yr < rp <20 yr	Low (L)	N	L	L	M
	2yr < rp <10 yr	Very Low (VL)	N	VL	L	L
	rp < 2 yr	No (N)	N	N	N	N

RISK LEVEL	
VH	Very High
H	High
M	Medium
L	Low
VL	Very Low
N	No

Damages occur only for very high and high risk levels

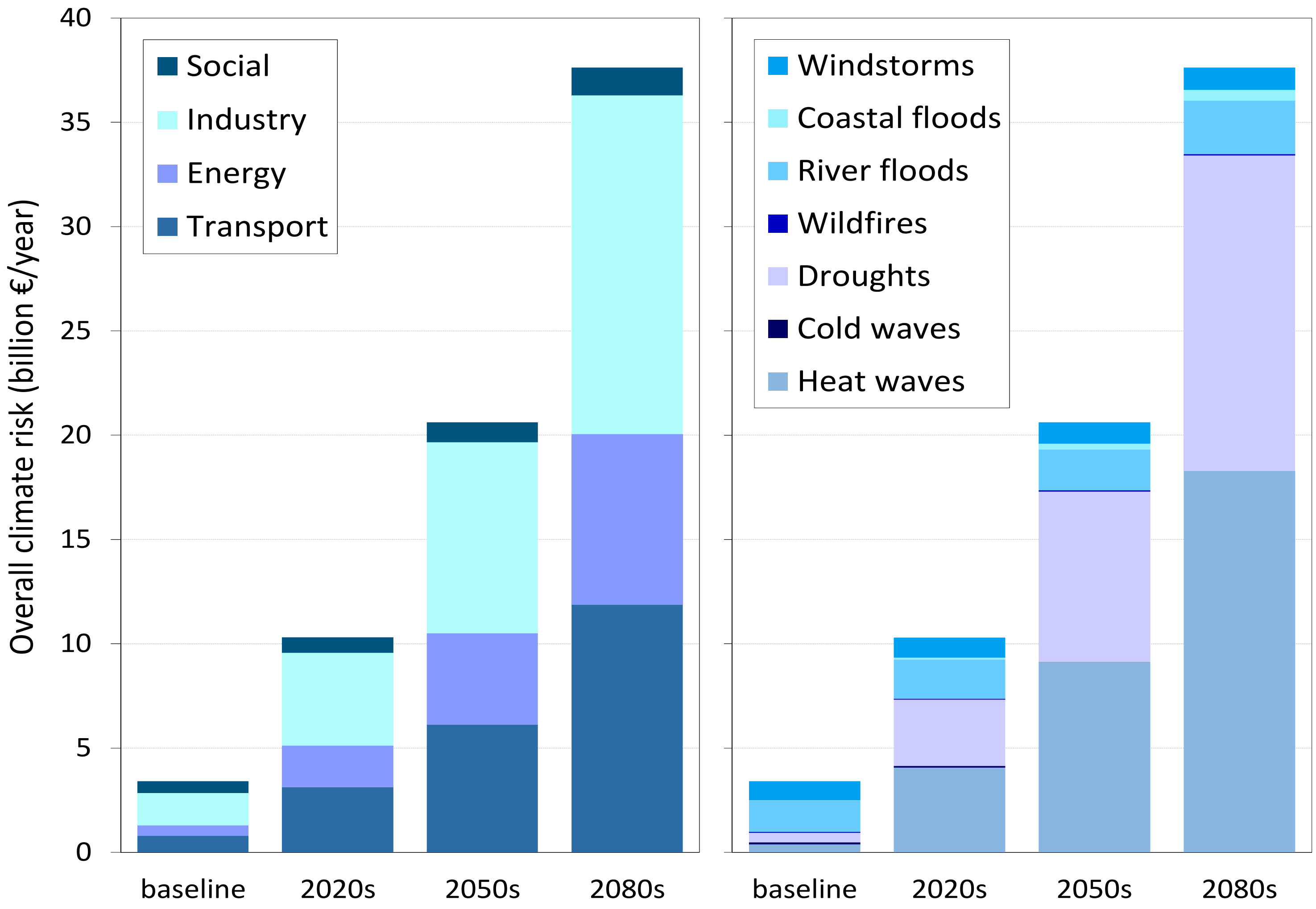
amount of assets in sector X in NUTS2 region Y **under very high and high risk levels** for hazard Z in **baseline**

baseline damages for sector X, NUTS2 region Y and hazard Z

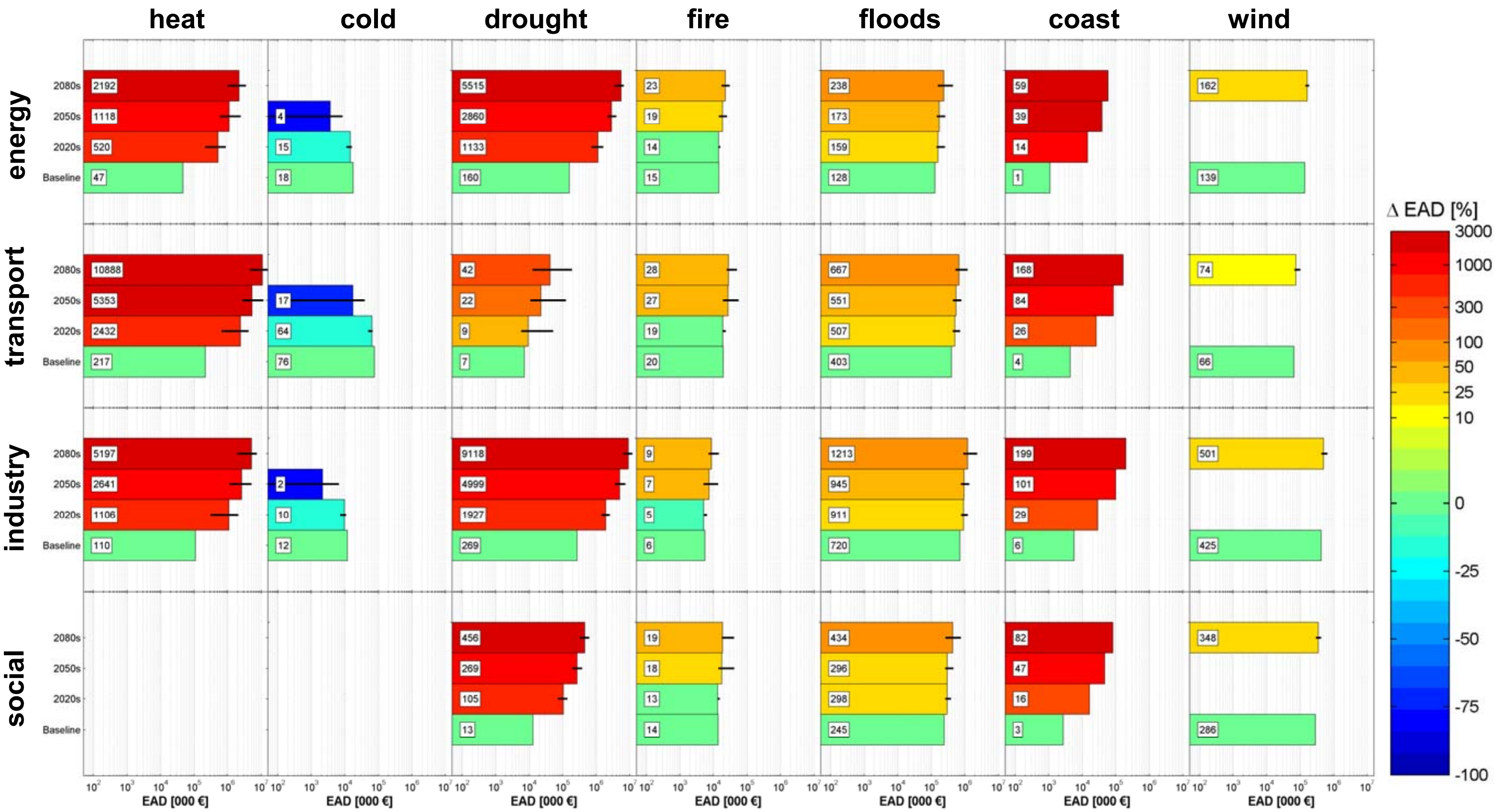
amount of assets in sector X in NUTS2 region Y **under very high and high risk levels** for hazard Z in **future time window**

future damages for sector X, NUTS2 region Y and hazard Z

CI – European aggregated damages

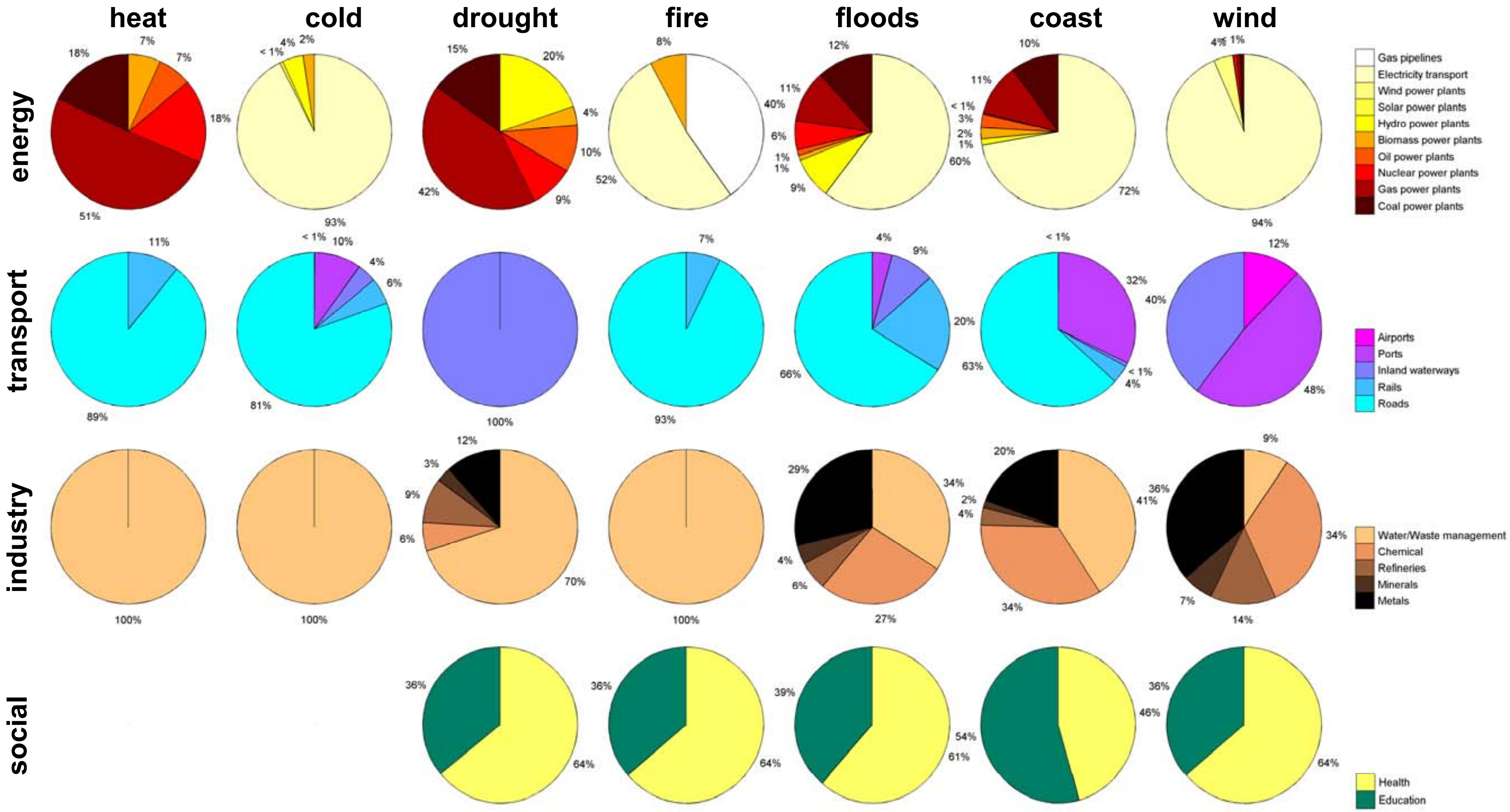


CI – damages per sector and hazard



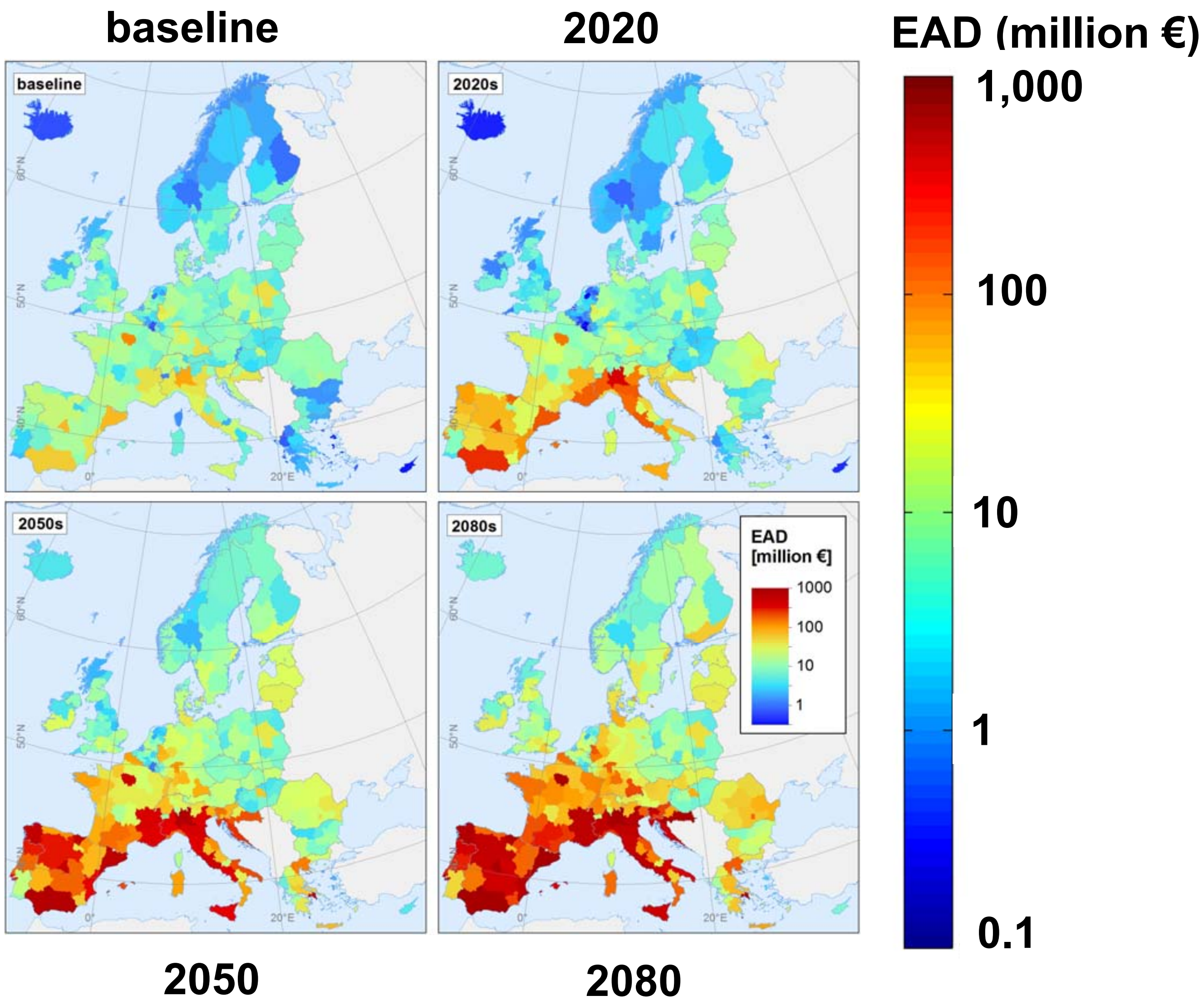
Expected annual damage aggregated at European level for each hazard, time period and sector

CI – damage distribution per sector



Distribution of Expected Annual Damage by hazard and infrastructure calculated over the 2011-2100 period

CI – multi-hazard multi-sector damages



Climate risks – key messages

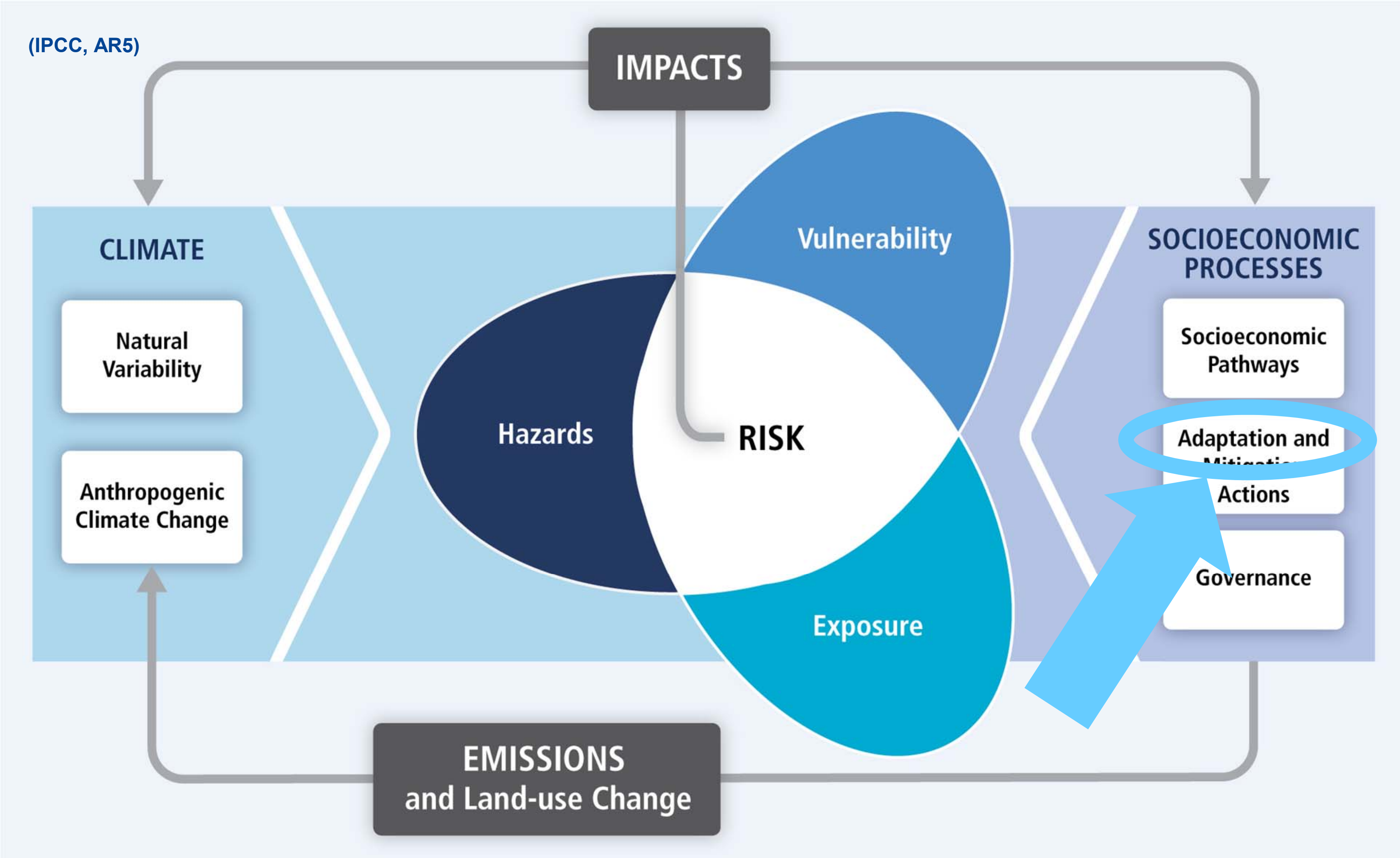
- **Very strong rise** in climate hazard **damages** to critical infrastructures and EU investments in Europe due to only climate change.

- Damages are **highest** for the **industry**, **transport** and **energy** sectors.

- Present climate hazard damages relate mostly to river floods (44%) and windstorms (27%). In the future **droughts** (52%) and **heatwaves** (40%) may **become the most damaging hazards**.

- **Southern European countries** will be most impacted.

Challenge 5: Adaptation



Categories of climate hazard mitigation measures

Category	Main goal	Main approach	Examples
Risk management planning, land-use planning, and climate adaptation	Vulnerability and exposure reduction	Regulation, legislation, communication, economic instruments	Spatial planning; zoning; adaptation strategies
Hazard modification	Hazard reduction	Technical, engineering	Cloud seeding; explosives for avalanches; retention areas for floods
Infrastructure	Hazard reduction	Technical, engineering	Reservoirs; dams; dikes; slope stabilization
Mitigation measures (stricto sensu)	Vulnerability reduction	Technical, economic instruments	Water conservation programs; hazard-proof building; reforestation
Communication (in advance of events)	Vulnerability reduction	Regulation, legislation, communication,	Education of public: hazard and risk maps; information on adequate behavior; experts' training
Monitoring and early warning systems (just before events)	Hazard reduction and vulnerability reduction	Technical, engineering, communication	Hydrological and meteorological monitoring; flood forecasting; extreme weather warning
Emergency response and evacuation	Vulnerability reduction	Technical, regulation, legislation, communication	Evacuation; emergency services and aid; response and recovery operations
Financial incentives	Vulnerability reduction	Regulation, legislation, communication, economic instruments	Finance institutions; subsidies; prerequisites for insurance coverage
Risk transfer	Vulnerability reduction and quick recovery	Regulation, legislation, economic instruments	Insurance; relief funds; donations; compensation

Bouwer et al., 2014

Reported Benefits / Costs adaptation

Adaptation measure	BCR (avg and range)	Region	Reference
Infrastructures			
Prevention of storm damage to buildings	2.7 (1.3 – 4.8)	Germany	Tröltzsch et al. (2012)
Local structural protection	1.7	Austria	Holub and Fuchs (2008)
Industry			
Awareness raising for companies	5.3 (1.0 – 9.7)	EU	Hjerp et al. (2012)
Energy			
Adaptation of electricity grids	5.1	EU26, without Malta	Hjerp et al. (2012)
High efficiency ventilation	1.8	EU26, without Malta	Hjerp et al. (2012)
Transport			
Improved road pavement materials and design standards	3	Germany and Austria	Doll et al. (2014)
Adapting tracks to higher temperatures	2 (0.34 - 9)	EU	Hjerp et al. (2012)
Adapting roads to higher temperatures	0.4 (0.2 - 0.9)	EU	Hjerp et al. (2012)
Adapting roads to increase in precipitation	0.5 (0.1 - 1.9)	EU	Hjerp et al. (2012)
Transport and spatial planning: general protection measures	1.3	EU	Doll et al. (2011)
Transport and spatial planning: network redesign	1.2	EU	Doll et al. (2011)
Infrastructure measures: incentives and information	2.4	EU	Doll et al. (2011)
Infrastructure measures: supervision and maintenance	1.2	EU	Doll et al. (2011)
Infrastructure measures: investments	1.5	EU	Doll et al. (2011)
Vehicle technologies: detection and communication	1.2	EU	Doll et al. (2011)
Vehicle technologies: vehicle engineering	1.9	EU	Doll et al. (2011)
Vehicle technologies: maintenance	1	EU	Doll et al. (2011)
Service operations: raising preparedness	1.4	EU	Doll et al. (2011)
Service operations: co-operation strategies	3.8	EU	Doll et al. (2011)
Service operations: system redesign	0.7	EU	Doll et al. (2011)
Cross-cutting			
Building dykes and beach nourishment	2.5	Germany	Tröltzsch et al. (2012)
Storm retention reservoirs	3.5 (0.5-9.4)	EU	Hjerp et al. (2012)
Action plan on Flood Defence for Rhine River	3.4	River Rhine (Germany)	Petrascheck (2003)
Flood and coastal risk management in England	7.5 (4 – 11)	UK	EA (2009)
Flood risk management plan in Belgium	4.1	Scheldt Estuary (Belgium)	Broekx et al. (2011)
Early warning for flash floods	9	Germany	EWASE (2008)
Groins	3.2 (1.6-4)	Greece	Kontogianni et al. (2014)
Beach nourishment	2.1 (0.4-3.8)	Greece	Kontogianni et al. (2014)
Revetments and geotextiles	3.7 (3.3-3.9)	Greece	Kontogianni et al. (2014)
Bulkheads	3.3 (2.4-3.9)	Greece	Kontogianni et al. (2014)

Indicative costs adaptation

- Average BCR = 2.5
- Benefits = 75% avoided damage
- No discounting
- 2020: accounting only for short term climate change
- 2050 medium term
- 2080 long term

	Accumulated total cost (in million €)		
Country	**2020**	**2050**	**2080**
AT	260	1,462	4,644
BE	7	610	1,962
BG	223	646	1,838
CH	543	3,683	9,634
CY	1	43	110
CZ	26	92	450
DE	1,839	11,374	29,518
DK	249	1,201	2,912
EE	40	245	517
ES	11,605	51,749	132,710
FI	127	587	1,453
FR	5,304	24,901	63,325
GR	1,095	11,067	24,483
HR	182	1,331	5,065
HU	0	472	1,395
IE	26	313	633
IS	0	38	98
IT	13,335	49,296	115,411
LT	89	350	655
LU	3	38	144
LV	72	318	569
MT	67	138	219
NL	34	644	1,570
NO	35	433	1,150
PL	43	203	453
PT	2,072	8,997	20,998
RO	847	2,323	6,629
SE	122	1,136	2,551
SI	106	543	2217
SK	14	522	1,988
UK	214	2,232	7,158
EU+	**39,297**	**181,789**	**461,166**

Indicative costs adaptation

- Capital cost = 30% total costs
- O&M costs spread in time
- Gross Fixed Capital Formation
- 2020: only short term climate change
- 2050: mid term
- 2080: long term

	Capital cost (in million €)			Capital cost (share GFCF)			Annual O&M cost (in million €)	
Country	2020	2050	2080	2020	2050	2080	2020	2080
AT	78	439	1,393	0.12	0.69	2.18	6.1	36
BE	2	183	589	0.00	0.23	0.74	0.2	15
BG	67	194	551	0.79	2.28	6.49	5.2	14
CH	163	1,105	2,890	0.16	1.10	2.88	13	75
CY	0	13	33	0.01	0.31	0.79	0.0	0.9
CZ	8	28	135	0.02	0.07	0.32	0.6	3.5
DE	552	3,412	8,856	0.11	0.68	1.77	43	230
DK	75	360	874	0.17	0.82	1.98	5.8	23
EE	12	73	155	0.39	2.35	4.97	0.9	4.0
ES	3,482	15,525	39,813	1.40	6.24	15.99	271	1,032
FI	38	176	436	0.09	0.43	1.07	3.0	11
FR	1,591	7,470	18,997	0.36	1.69	4.31	124	493
GR	328	3,320	7,345	0.83	8.36	18.50	26	190
HR	55	399	1,519	0.57	4.17	15.87	4	39
HU	0	142	419	0.00	0.71	2.09	0	11
IE	8	94	190	0.03	0.32	0.64	0.6	4.9
IS	0	11	29	0.01	0.81	2.10	0.0	0.8
IT	4,001	14,789	34,623	1.25	4.62	10.82	311	898
LT	27	105	196	0.57	2.22	4.16	2.1	5.1
LU	1	11	43	0.01	0.16	0.60	0.1	1.1
LV	22	95	171	0.62	2.77	4.96	1.7	4.4
MT	20	42	66	1.42	2.94	4.65	1.6	1.7
NL	10	193	471	0.01	0.15	0.38	0.8	12
NO	10	130	345	0.02	0.19	0.52	0.8	8.9
PL	13	61	136	0.02	0.08	0.19	1.0	3.5
PT	622	2,699	6,299	1.68	7.31	17.05	48	163
RO	254	697	1,989	0.77	2.12	6.05	20	52
SE	37	341	765	0.04	0.41	0.93	2.9	20
SI	32	133	665	0.41	2.11	8.61	2	17
SK	4	157	596	0.03	1.05	4.00	0.3	15
UK	64	670	2,147	0.02	0.23	0.74	5.0	56
EU+	**11,789**	**54,537**	**138,350**	**0.42**	**1.93**	**4.84**	**917**	**3,587**

Adaptation – key messages

- Current design, construction, operation and maintenance **standards and practices** of critical infrastructures need to be **amended** in view of climate change.

- **Adaptation** strategies can offer impressive prospects to **increase** the **resilience** of critical infrastructures against future climate.

- Some **regions** face **substantial investments** to prepare their critical infrastructures against future climate hazards.

- Promote **cross-sectoral** consideration of adaptation and climate resilience.

- Preference for **no- or low-regret** measures, inclusion of **safety margins** and **reversible/adaptable** strategies.

Limitations – future challenges

- Uncertainty **climate hazard** projections.
- Potential data incompleteness on **exposed assets**.
- Infrastructure-specific **vulnerability** depends on the institutional, economic, and technological context.
- Estimates of baseline and future **damages** are fully conditional on those **reported** by EMDAT and Munich Re.
- The proposed **disaggregation of losses across sectors** and regions may not reflect the true sectorial-specific regional impacts.
- **Benefit and costs** relations of **adaptation** measures in a specific setting may deviate strongly from the average literature-derived value used herein.
- **Non-monetary** and **non-market consequences** not considered.

Final note

the myriad of climate change impacts go far beyond those of the 7 climate hazards to the critical infrastructures considered in this study; hence, it should be kept in mind that the **damages presented here only reflect a fraction of the potential climate change impacts to society in Europe**