Escalating economic impacts of weather-related extremes on critical infrastructures in Europe under climate change

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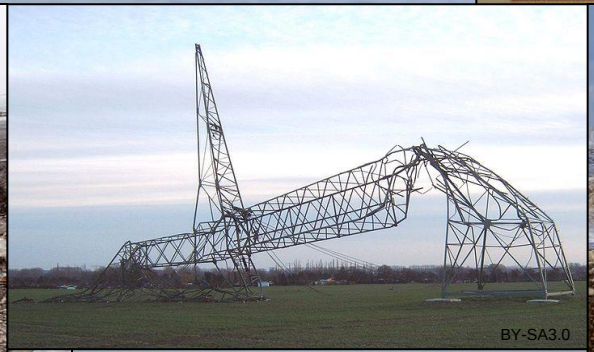
Definition:

Critical infrastructures (CI) refer to the array of physical assets, functions and systems that are vital to ensuring the health, wealth, and security (European Council, 2008)

CNN


National Geographic


Travel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Dalje


Stuart McMahon


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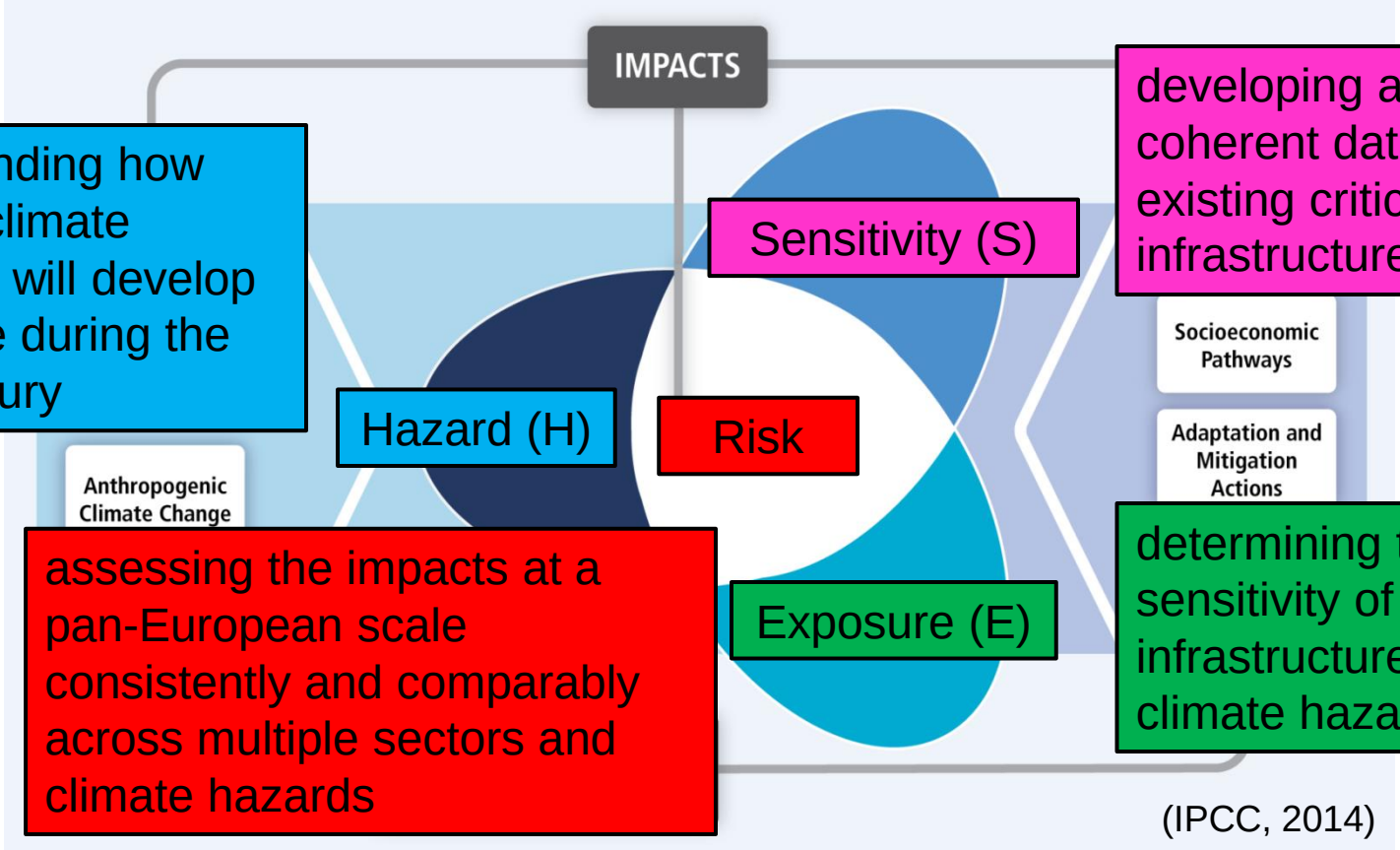
Background

- **Focus mostly on single hazards or a limited set of hazards** (Arnell et al., 2013; Ciscar et al., 2011; Lung et al., 2013)
- **Refer to broad sectorial categories** (Hsiang et al., 2017; Piontek et al., 2014; van Vliet et al., 2012)
- **Impacts of climate extremes on infrastructures primarily presented in qualitative terms** (Cruz and Krausmann, 2013; Michaelides et al., 2014; Schaeffer et al., 2012)
- **Difficulties in establishing comparisons across hazards and sectors** (Kappes et al., 2012)
- **Datasets of existing infrastructures lack homogeneity** (Fekete et al., 2016)

Overall goal

Comprehensive multi-hazard risk assessment of critical infrastructures in Europe under climate change

Methodological framework



understanding how multiple climate extremes will develop in Europe during the 21st century

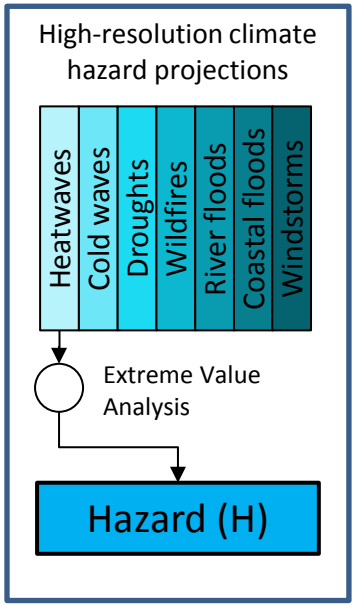
developing a spatially coherent dataset of existing critical infrastructures

assessing the impacts at a pan-European scale consistently and comparably across multiple sectors and climate hazards

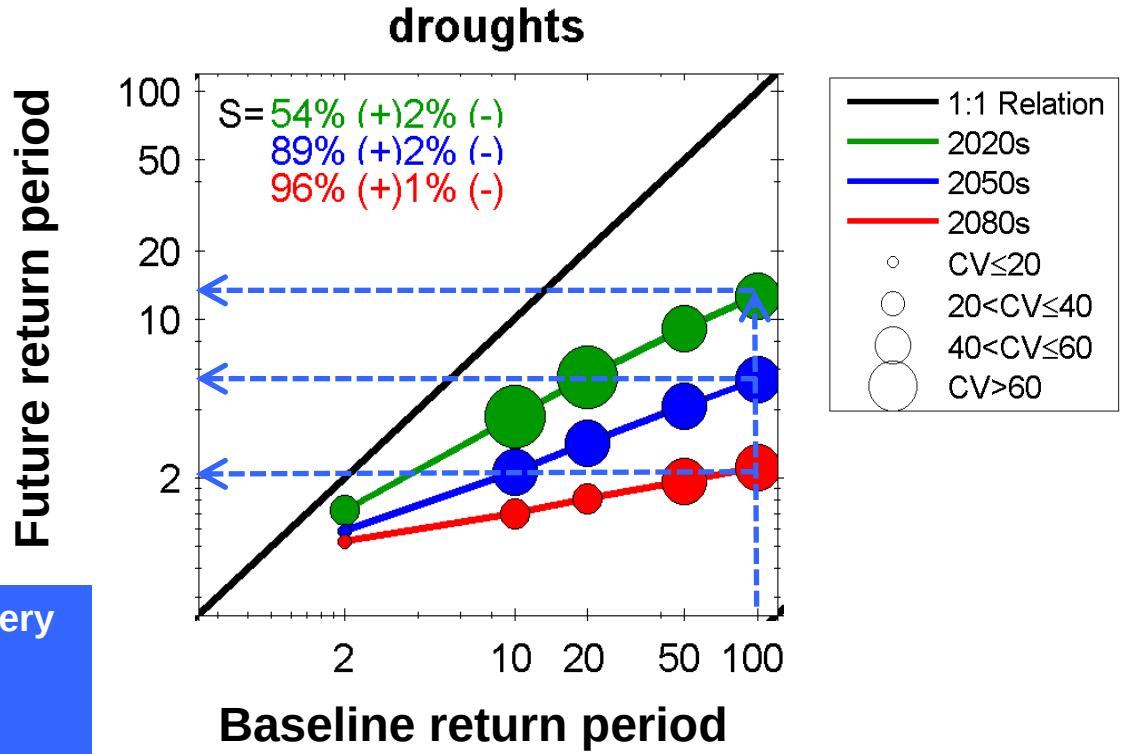
determining the sensitivity of critical infrastructures to climate hazards

(IPCC, 2014)

Climate hazards

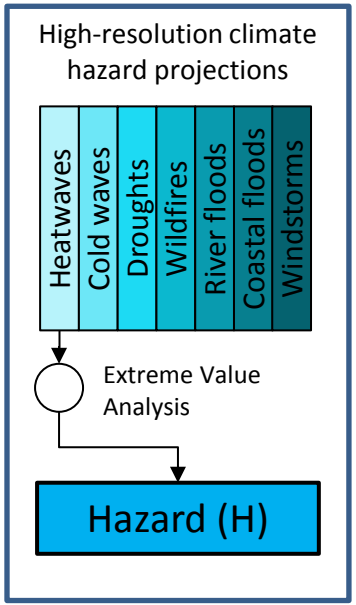


Changes in frequency of extreme events



Current 100-year event to happen every
~12 years in 2020s
~5 years in 2050s
~2.5 years in 2080s

Climate hazards



T_R > 100 yr → **Very high (VH)**

50 yr < T_R <100 yr → **High (H)**

20 yr < T_R < 50 yr → **Moderate (M)**

10 yr < T_R <20 yr → **Low (L)**

2yr < T_R <10 yr→ **Very Low (VL)**

T_R< 2 yr → **No (N)**

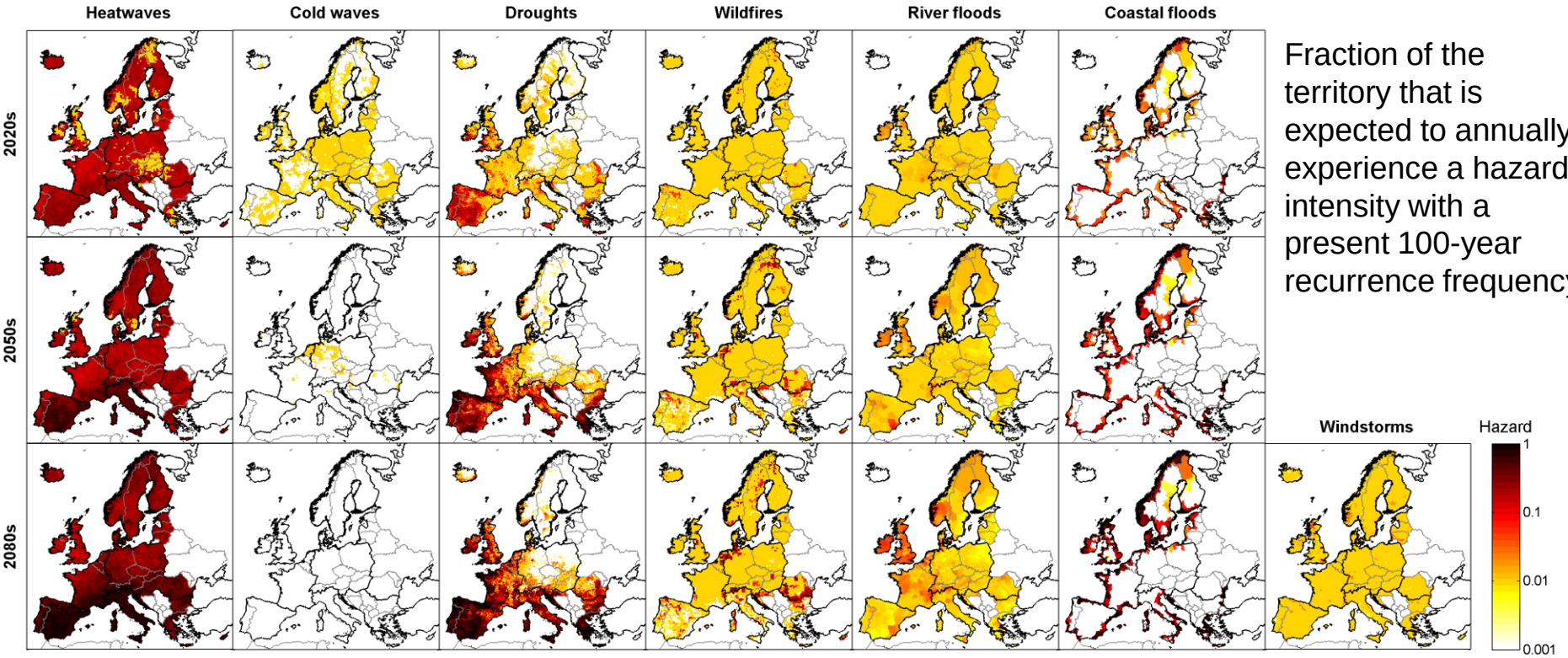
Intensity of hazard that under current climate conditions has the probability to occur less than once in 100 years

events which in current climate happen every 20 years or more frequent are considered as having low intensity

Expected annual fraction exposed $H = \int_0^{\frac{1}{T_R}} f \, \mathrm{dp}$

f is the exposure-probability function

Climate hazards



Fraction of the territory that is expected to annually experience a hazard intensity with a present 100-year recurrence frequency

Forzieri et al., 2016 CC

Exposure data collection/harmonization

Detailed representation of sectorial physical assets and productive systems

GIS data collection of infrastructures

Sector	Infrastructure type
Transport	Local roads
	Roads of national importance
	Motorways
	Railways
	Inland waterways
	Ports
	Airports
Energy	Coal power plants
	Gas power plants
	Oil power plants
	Nuclear power plants
	Biomass and geothermal power plants
	Hydro power plants
	Solar power plants
	Wind power plants
	Electricity distribution/transmission
	Gas pipelines
Industry	Metal industry
	Mineral industry
	Chemical industry
	Refineries
	Water and waste treatment
Social	Education infrastructure
	Health infrastructure

Exposure data collection/harmonization

Detailed representation of sectorial physical assets and productive systems

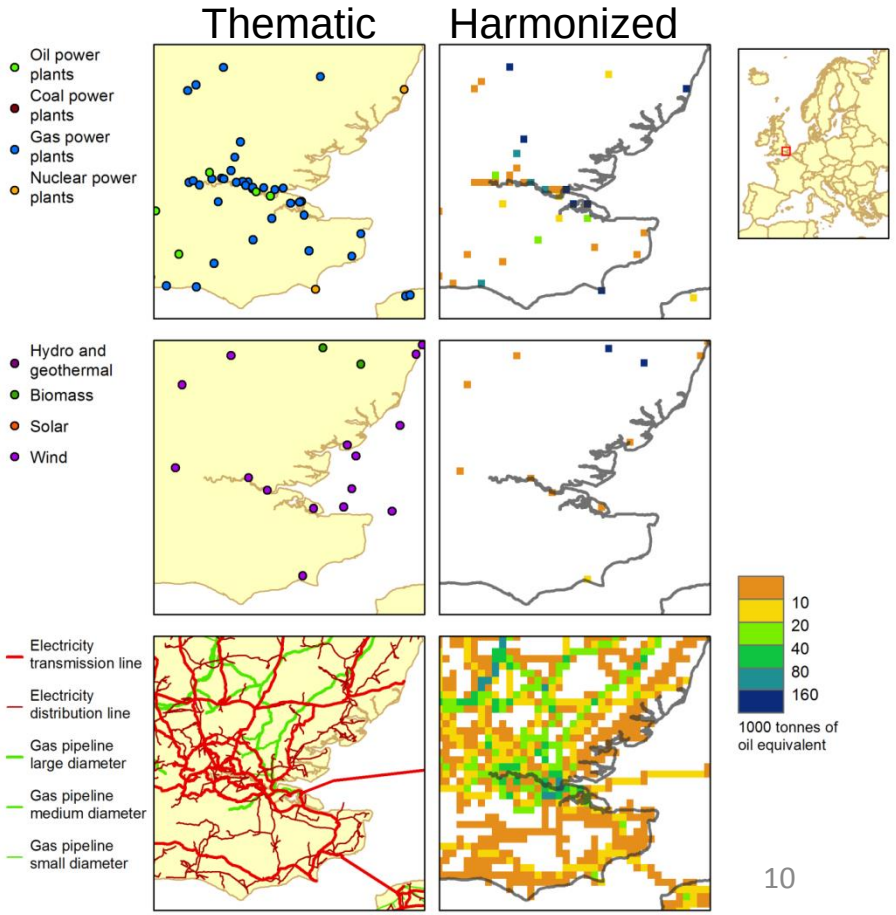
GIS data collection of infrastructures

Eurostat Intensities

Data harmonization

Exposure (E)

Example of harmonized energy infrastructure layers.



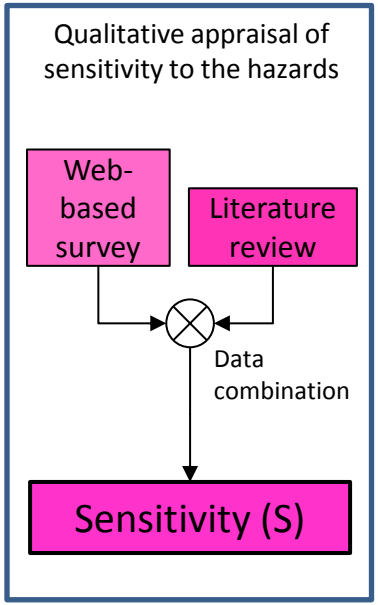
$w_{j,i}$ are the weights of infrastructure *j* in pixel *i*

$$Y_{j,i} = X_{j,Z}\left(w_{j,i} / \sum_{i \in Z} w_{j,i}\right)$$

total of infrastructure *j* in country *Z*

intensity of infrastructure *j* in pixel *i*

Climate sensitivity of CI (*S*)



Expert survey

~ 500 experts for each sector

academics + field experts

editorial boards

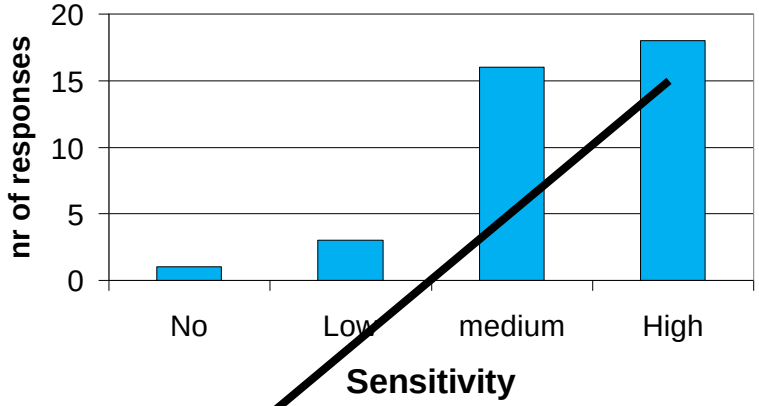
sector specific

climate impact experts

~ 10% responses

40-50 answers/sector

Sensitivity of railways to floods



Sector	Infrastructure type	Heatwaves	Cold waves	Droughts	Wildfires	River and coastal floods	Windstorms
Transport	Local roads						
	Roads of national importance						
	Motorways						
	Railways						
	Inland waterways						
	Ports						
	Airports						

Sensitivity matrix

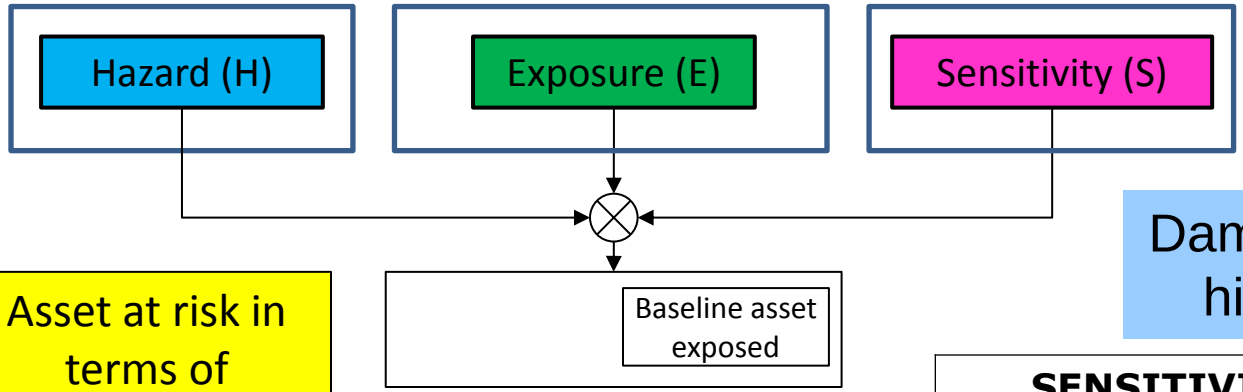
HIGH

MEDIUM

LOW

NO

Risk integration



Asset at risk in terms of intensity value

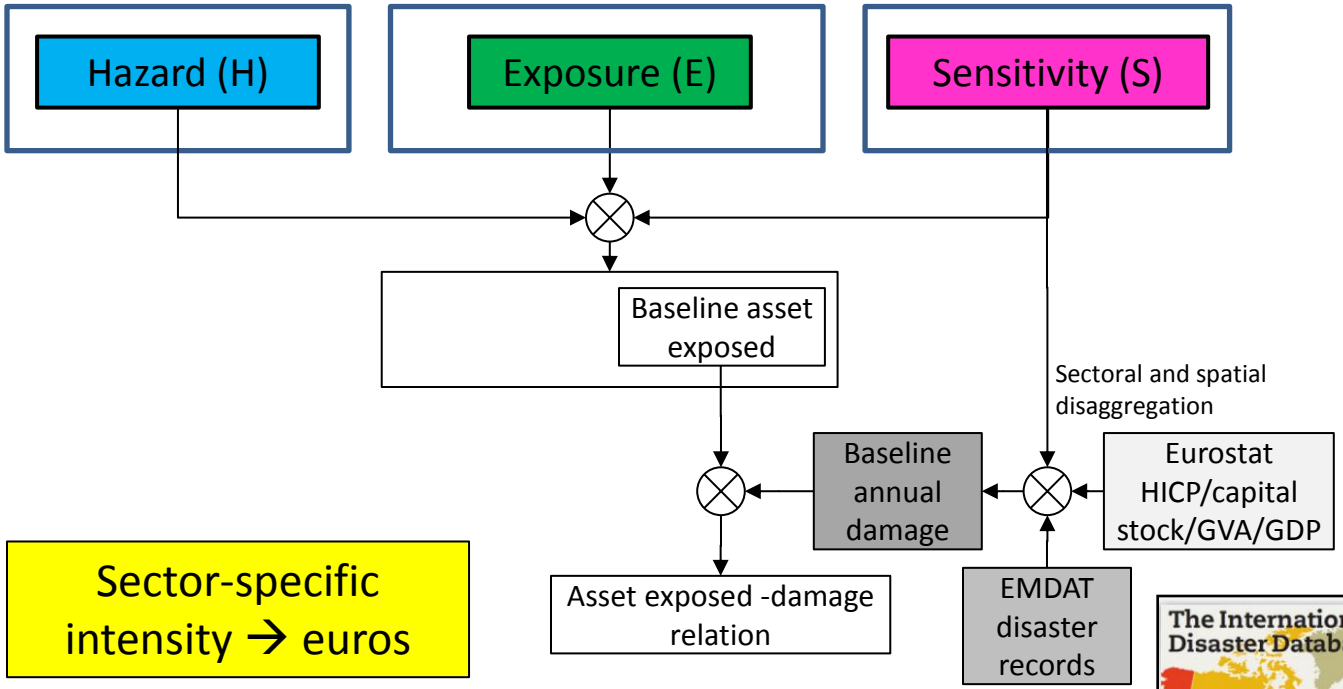
Damages occur only for very high and high risk levels

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

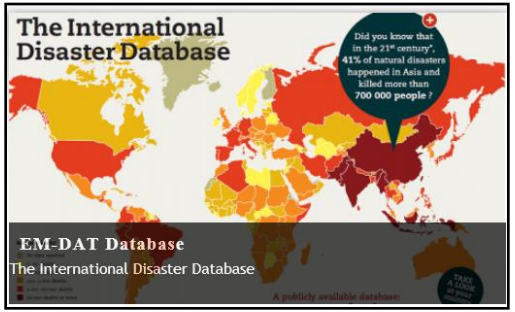
RISK LEVEL

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

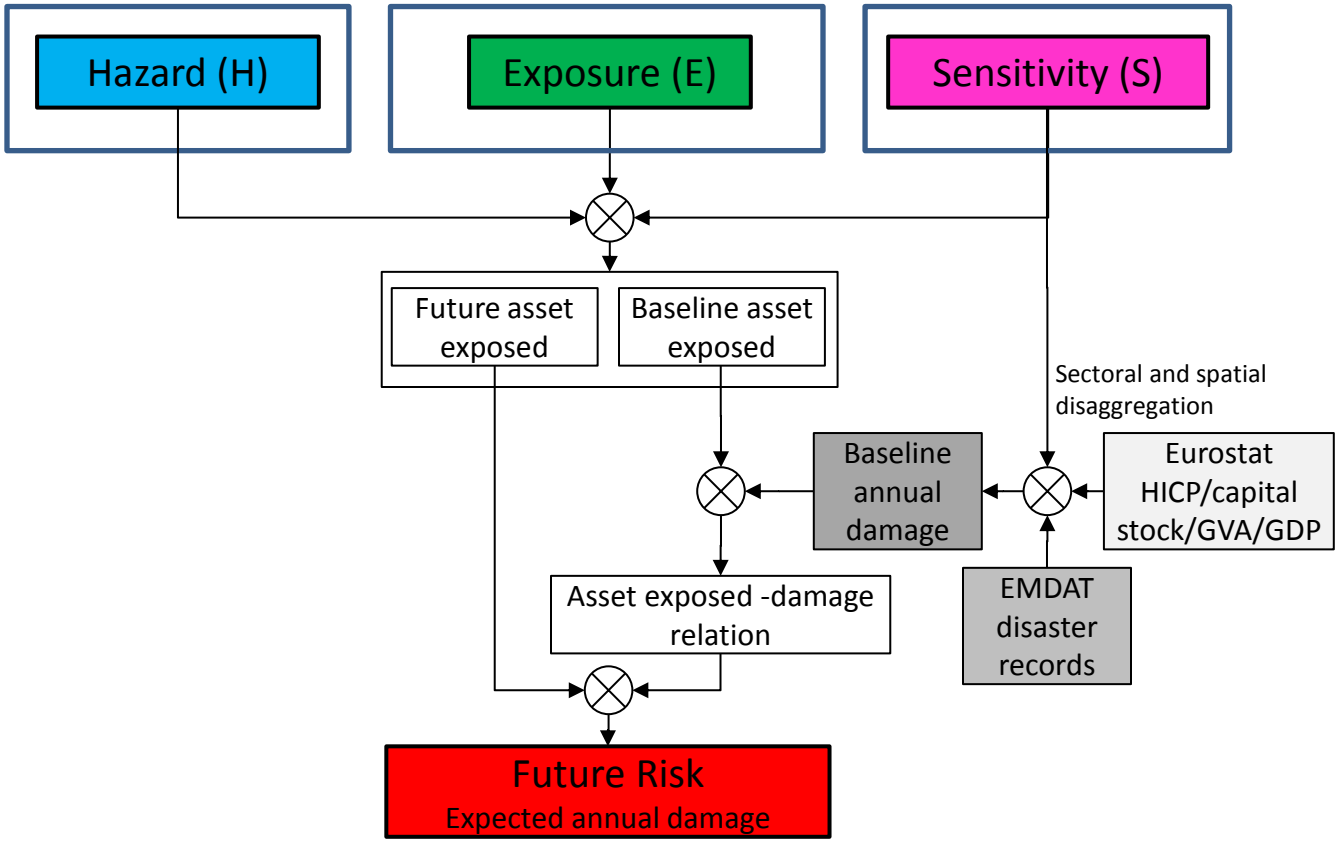
Risk integration



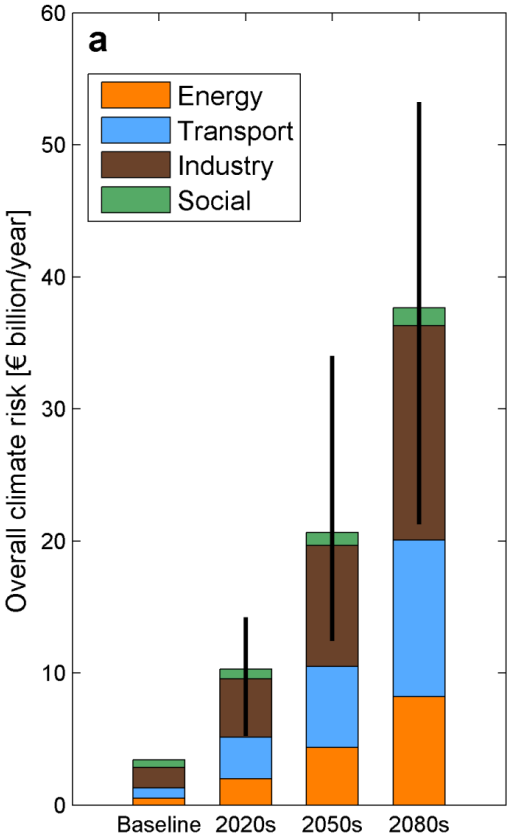
Sector-specific intensity → euros

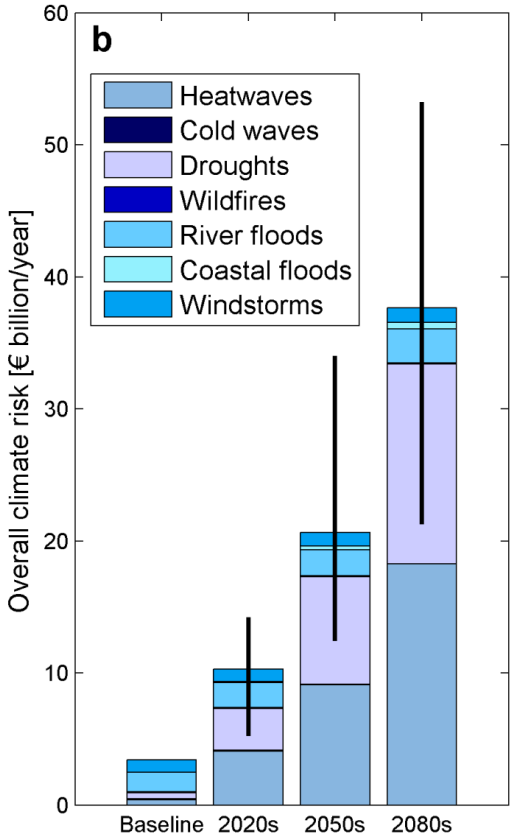


Risk integration



Overall multi-hazard multi-sector risk



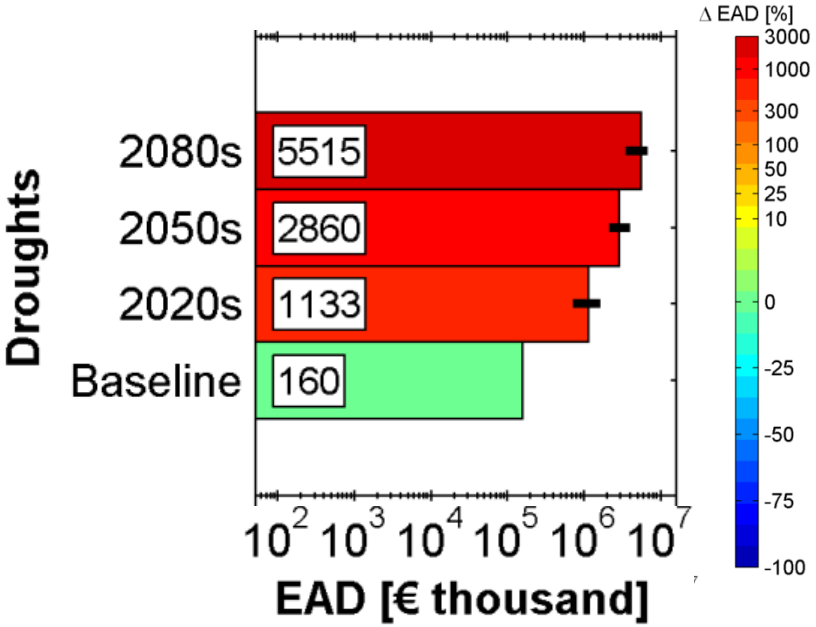


Overall climate hazard risk to critical infrastructures aggregated at European level (EU+) for each time period: a) distribution of damage by sector; b) distribution of damage over the seven hazards.

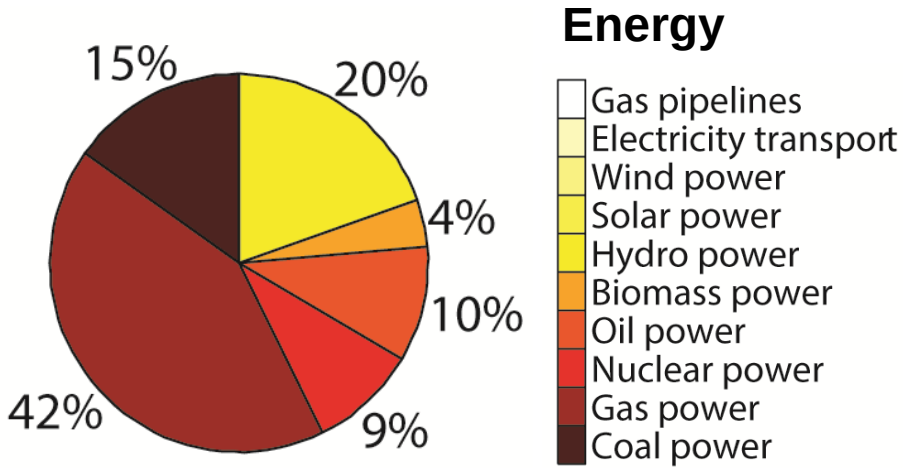
Forzieri et al., in review
GEC

Sector- and infrastructure-level risks

Impacts on energy infrastructures due to droughts



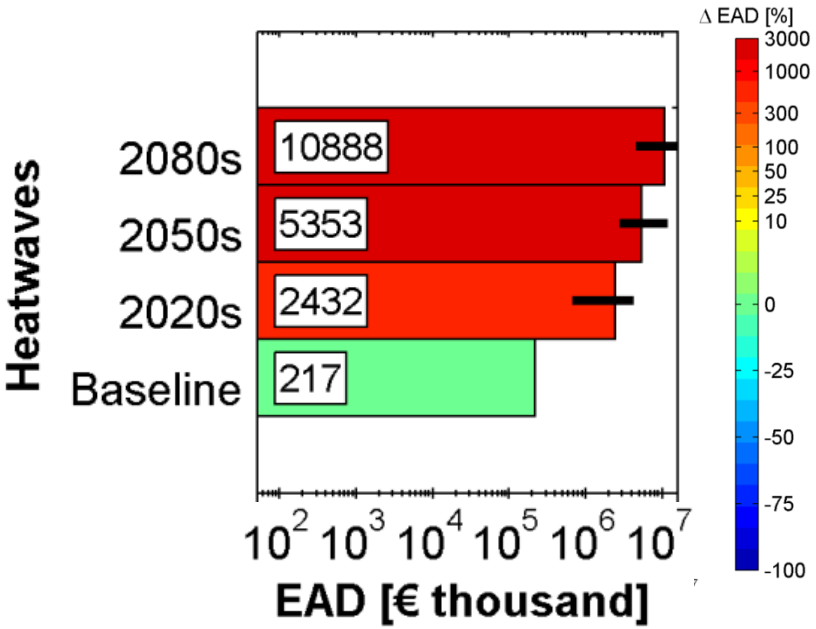
Expected annual damage (EAD) to critical infrastructures aggregated at European level (EU+)



Distribution of hazard impacts over infrastructures types, calculated over 2011-2100.

Sector- and infrastructure-level risks

Impacts on transport infrastructures due to heatwaves



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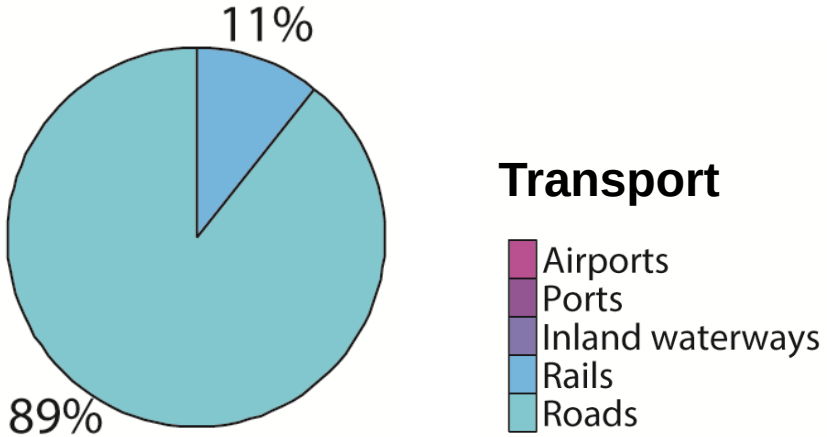

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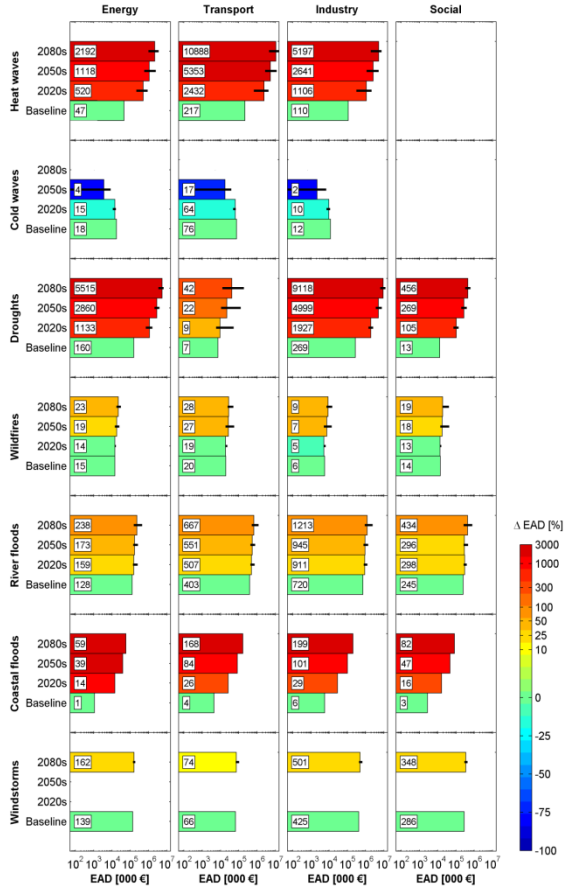
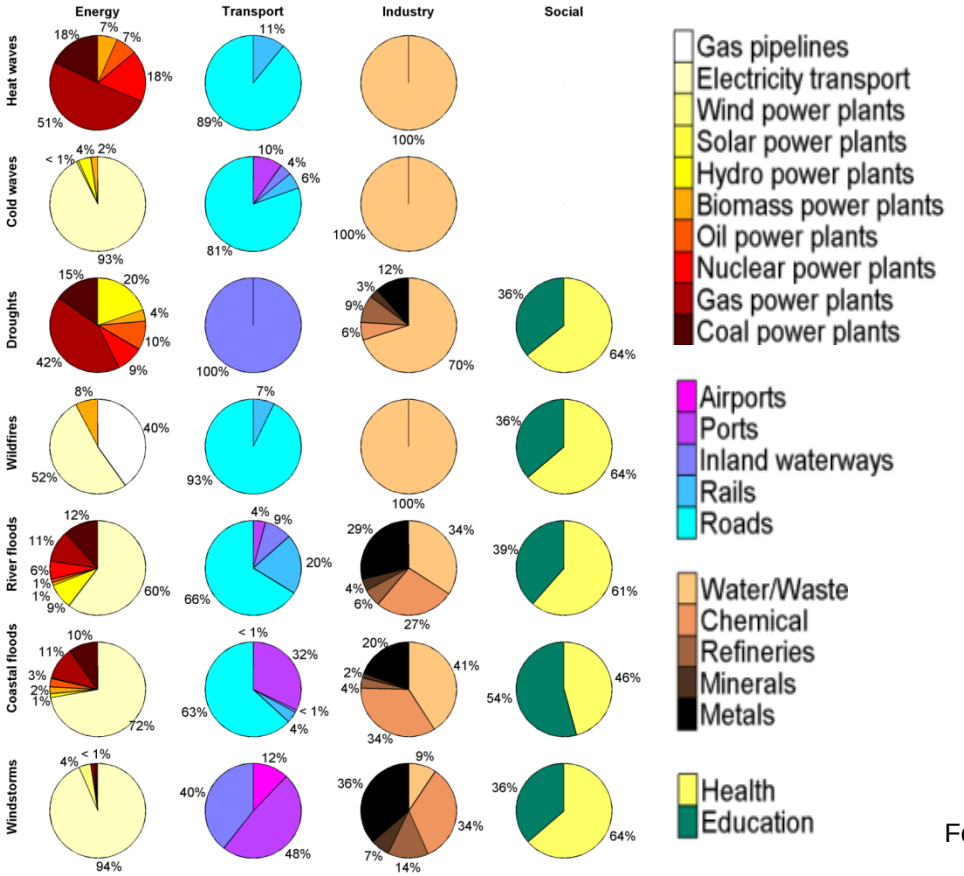
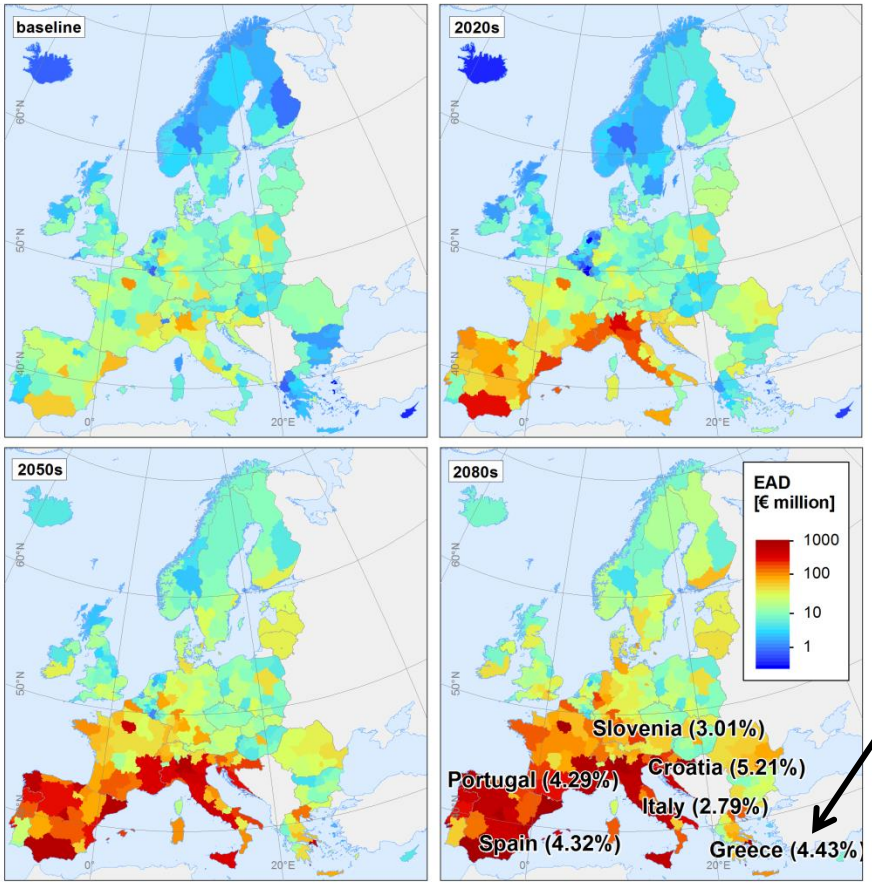




Forzieri et al., in review GEC

Space-time variations of risks



Spatial patterns of overall climate hazard risk to critical infrastructures in the different time periods.

Proportion of gross fixed capital formation (GFCF, a measure of the annual investments in fixed assets) at risk

Forzieri et al., in review
GEC

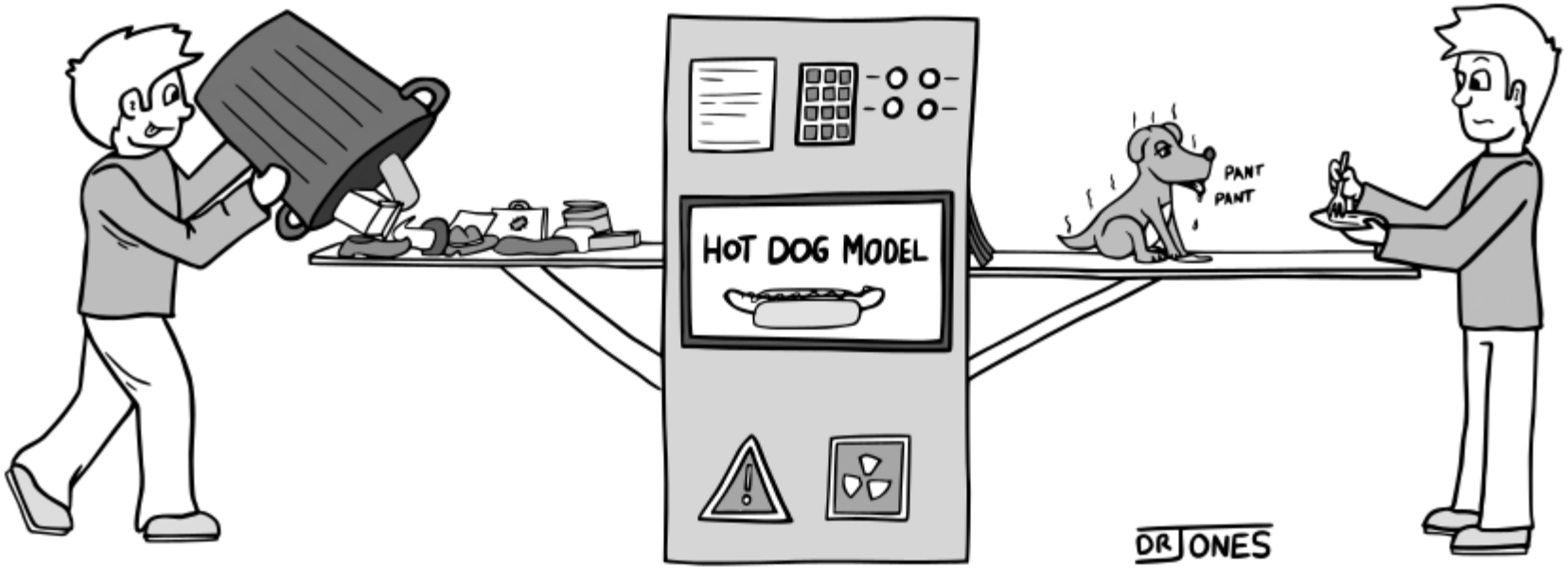
Main limitations and knowledge gaps in methodological and data aspects

- **Deviations of the reported damage** from the true impacts are inherently translated into our damage estimates
- **Assumptions beyond the proposed disaggregation** of losses represent potential sources of uncertainty
- **Hazard interrelations or cascade effects** are not accounted
- Vulnerability as derived from the survey does not account for **different degrees of interconnectivity, technological heterogeneity, and the life span of infrastructures**
- **Sector-interdependencies and cascading effects** are not explicitly modelled

Conclusions

- **Impacts could rise up to 10 times present damages by 2100 due to global warming**
- **Damages from heatwaves, droughts and coastal floods show the most dramatic rise**
- **Economic losses could be highest for the industry, transport and energy sectors**
- **Southern and south-western European countries will likely be most affected**

Better data are crucial to properly assess current and future disaster risk and to evaluate the cost-effectiveness of risk reduction and adaptation strategies



because our models are only as good as their input

Cross-comparison analysis

Cross-comparison analysis of expected annual damage (EAD) due to river floods. Multi-sector ensemble median of EADs obtained by Rojas et al. (2013; RA2013) versus our estimates – FA2017 – (on *x*- and *y*-axis, respectively) for each country (circles) and time slice