The Great Inundation: Sea-Level Rise and the Remaking of Europe's Economic Landscape

Theodoros Chatzivasileiadis

TU Delft

Co-authors: Ignasi Cortés Arbués, Tatiana Filatova, Servaas Storm, Olga Ivanova, Francesco Bosello

Planbureau voor de Leefomgeving

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Thanks to the SC3 Team (Socio-economic Complexity of Climate Change)

Prof. Tatiana Filatova

Ignasi Cortes Arbues

Dr. Alessandro Taberna

Liz Verbeek

Thorid Wagenblast

Joos Akkerman

Asli Mutlu

Dr. Sofia Gil-Clavel

Web: http://www.sc3.center/
Twitter: @sc3_team
BlueSky: @sc3team.bsky.social

Email: t.chatzivasileiadis@tudelft.nl

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The bigger picture (methodologically)

- Physical risks from CC are looming. Quantitative assessments of such risks is critical for understanding their **scale** (and whether the potential impact for the economy and society are manageable or systemic) as well as for the **design of effective CCA policy.**

- Economic assessments of such risks include:

  - **Direct damages**: like physical damage to residential and industrial areas and public infrastructure. They are well estimated for many climate-induced risks at various scales from global (by IAMs, like IMAGE of PBL) to national and regional

The bigger picture (methodologically)

- Indirect damages like cross sectoral, cross regional, business interruption, etc., pure economically-driven business relocation, even impact on the national debt and financial implications, usually done with IO or CGE models.

- **Highly important**: huge uncertainty (range from 10-150% of direct damages) but are so far estimated only at the scale of entire country because of methodological and data limitations

- In a way we are assuming that the economic activity is evenly spread over the country when a CC shock hits it.

- These assessments may underestimate physical climate risks and **are not actionable for the design of CCA policies.**

- Let us consider a case of SLR…

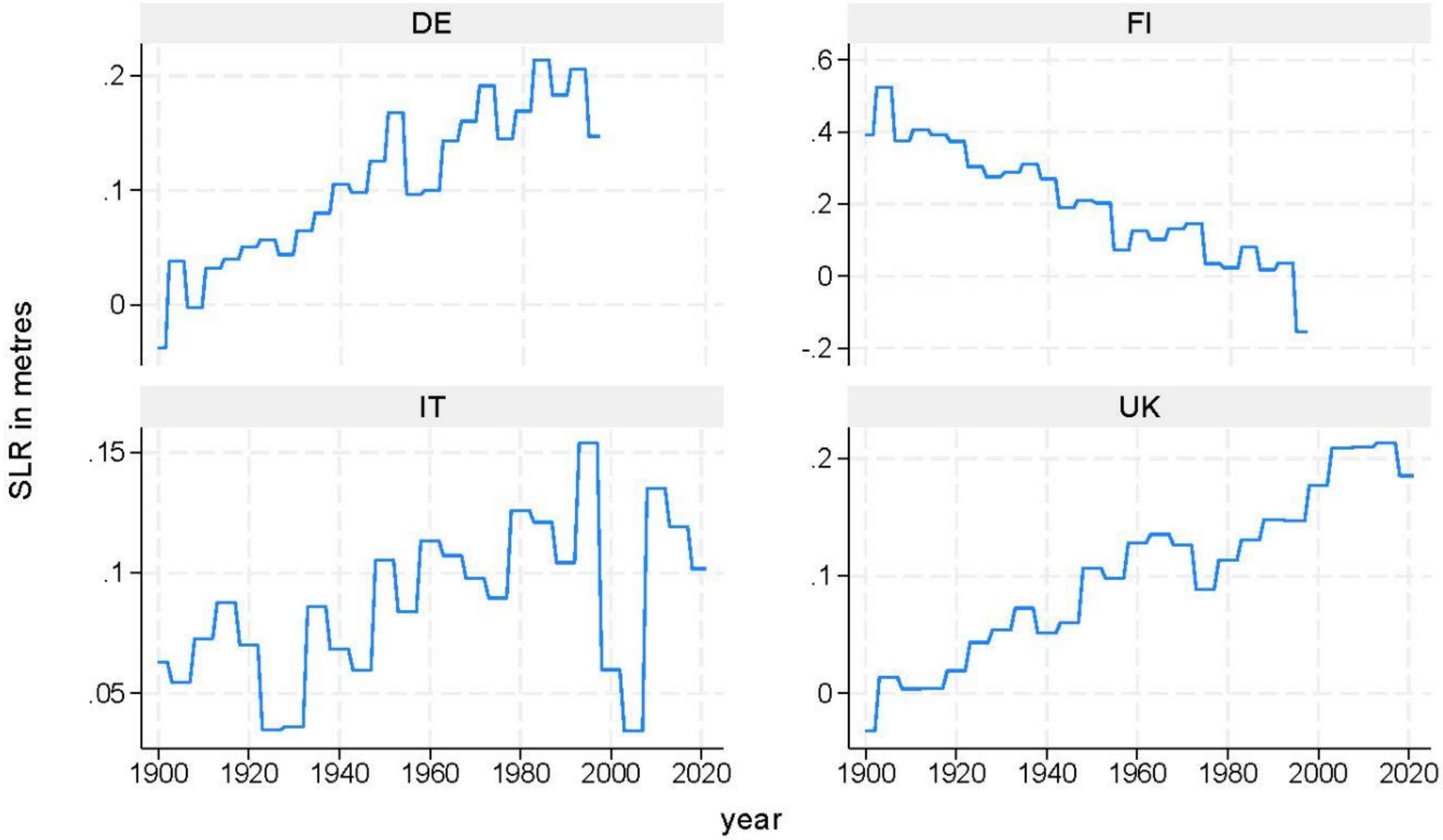
Understanding indirect climate change damages

- **Direct damages** from coastal flooding deplete the capital stock of firms and the housing stock.
  - **Business interruption** and **labour disruption** following a flood are short-term effects, and not explicitly modelled.

- Our analysis goes **beyond physical/direct damages** as indirect economic impacts can grow with disaster size (Hallegatte, 2008), as the aftermath of Katrina and Sandy taught us.

- Some of the common forms of indirect damages following a (flooding) disaster:
  - Inter-sectoral supply-side effects
  - Final demand effects
  - Fiscal impacts

Sea-level rise (SLR) up to 2020



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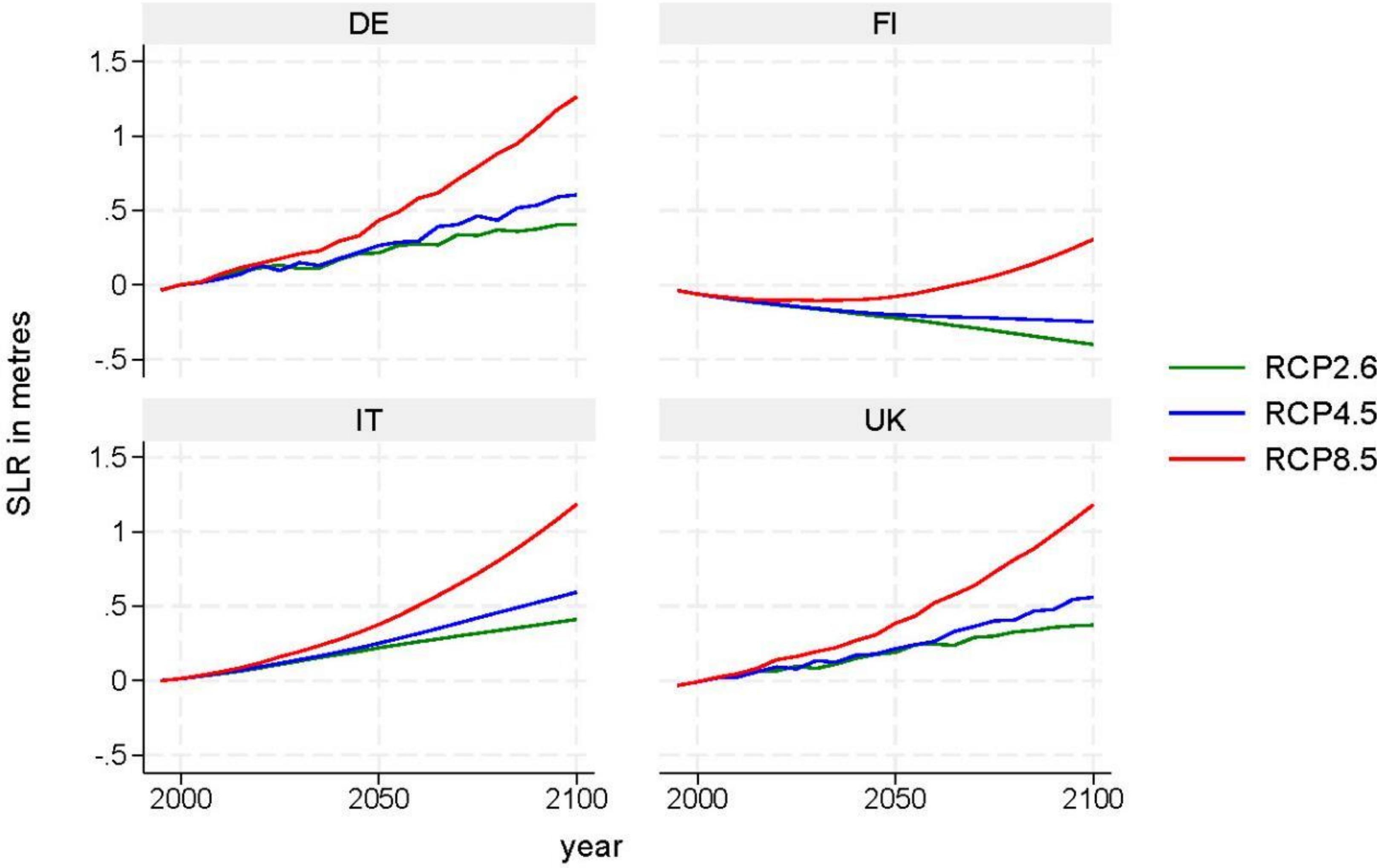
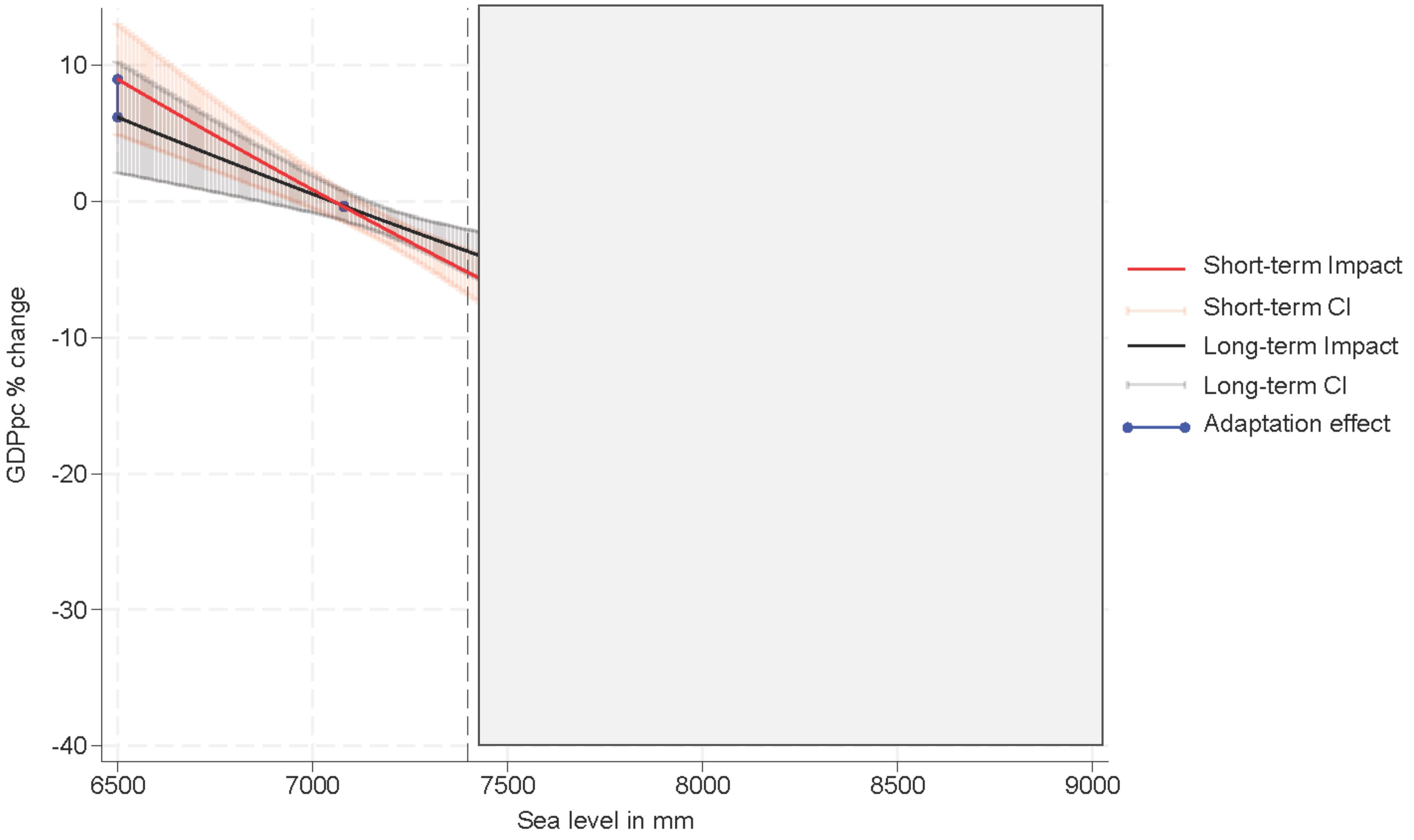
For data see: https://psmsl.org/

Projected SLR up to 2100



For data see: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool

And some historical estimations..



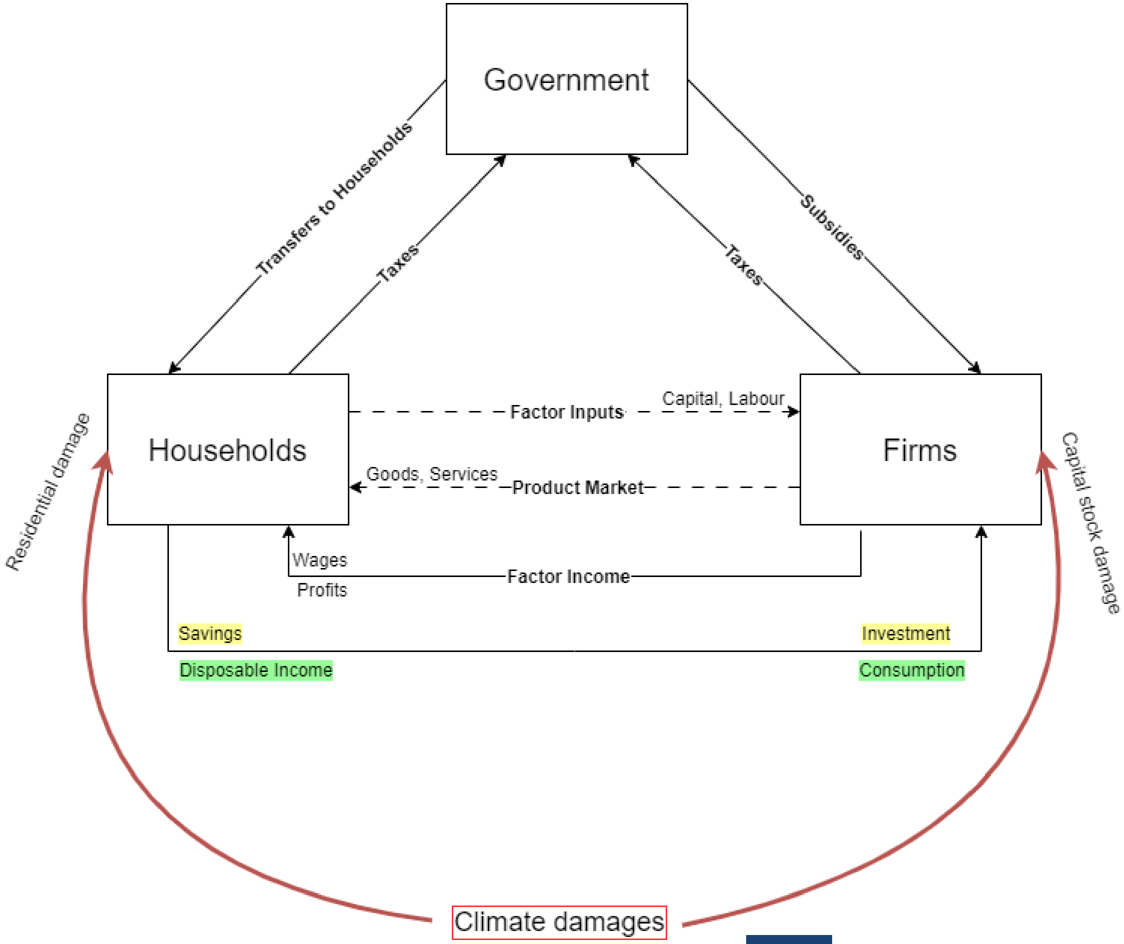
Motivation

- **Sea-level rise (SLR)** has great disruptive potential in the long term.
  - 44% of the EU and UK populations (~200 million) live within 50km of the coastline.
  - Coastal regions represent ~40% of European GDP.
  - 75% of Europe's international trade volume occurs on maritime routes.
  - The susceptibility of the European coast to coastal flooding is not homogenous (Vousdouskas et al., 2020).

Methods: Computable General Equilibrium (CGE) modelling

- <u>EU-EMS</u>: Spatial computable general equilibrium (SCGE) model built by PBL Netherlands (Ivanova et al., 2019).

- Multi-regional input-output (MRIO) table for **271 NUTS2 regions of the EU27&UK** (and the rest of the world).
- The model is recursive dynamic, involving capital accumulation and technology progress, which link temporal equilibria at every time step.
  - 5-year steps from 2015 to 2100



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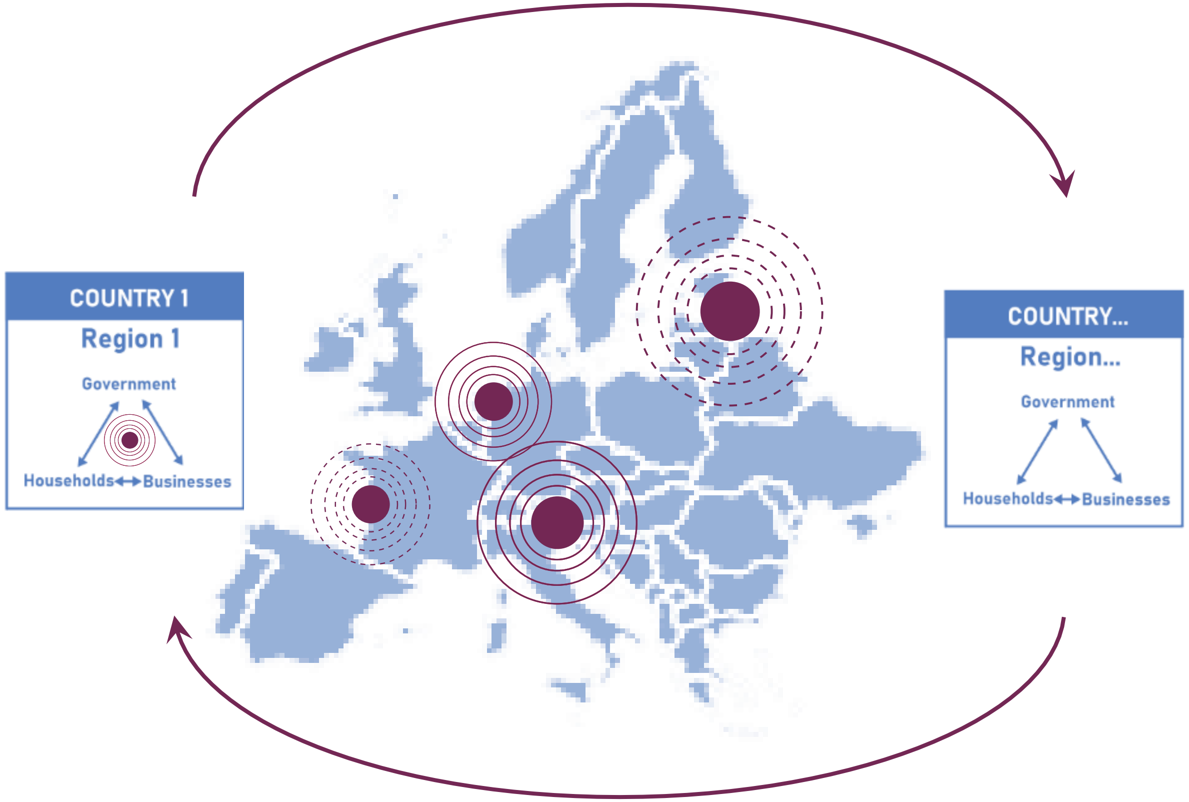
Methods (II): Shocking the European economy



- We obtain **direct economic damages to European regions from SLR** from previous research (Lincke et al., 2021), in 5-year steps.
- We **distribute the direct damages** among sectors in each region based on **their exposure to flooding**. This is it is per sector per region and that it is unique
- Permits for the first time to do a bottom-up allocation of indirect damages to regions and sectors so that a CGE can trace cross regional and cross sectoral indirect damages
- There are 271-by-9 unique sectors in the model **each affected differently**, increasing the **accuracy** of our results.

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Methods (III): Forced recovery of critical infrastructure sectors

- The model features a global investment agent that allocates available savings based on the returns to capital of different sectors (Pant, 2015).
  - A relatively 'under-invested' sector will have large returns to capital.

- However, we force the model to recover 'critical' sectors first, emulating what might happen in a real economy.

- The **critical sectors** are: Public Services, Transport, Utilities and Logistics.
- 'Recovery' implies the <u>recovery of the sectoral capital stock</u> to the level before the shock.

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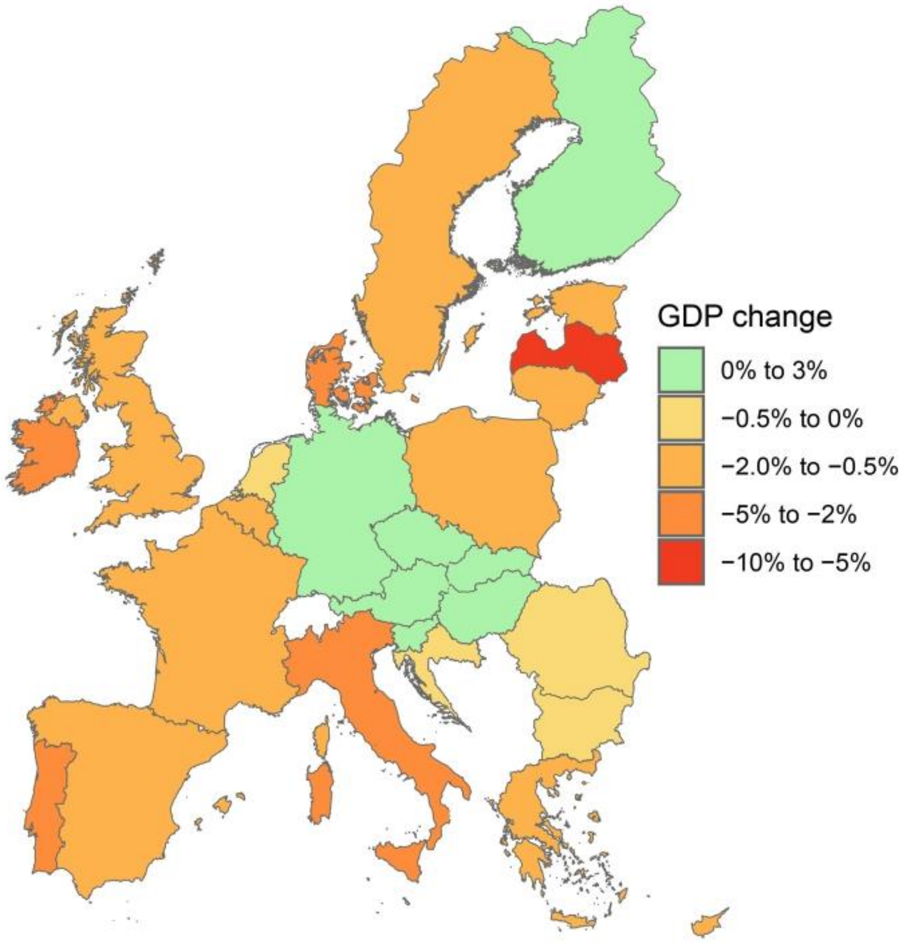
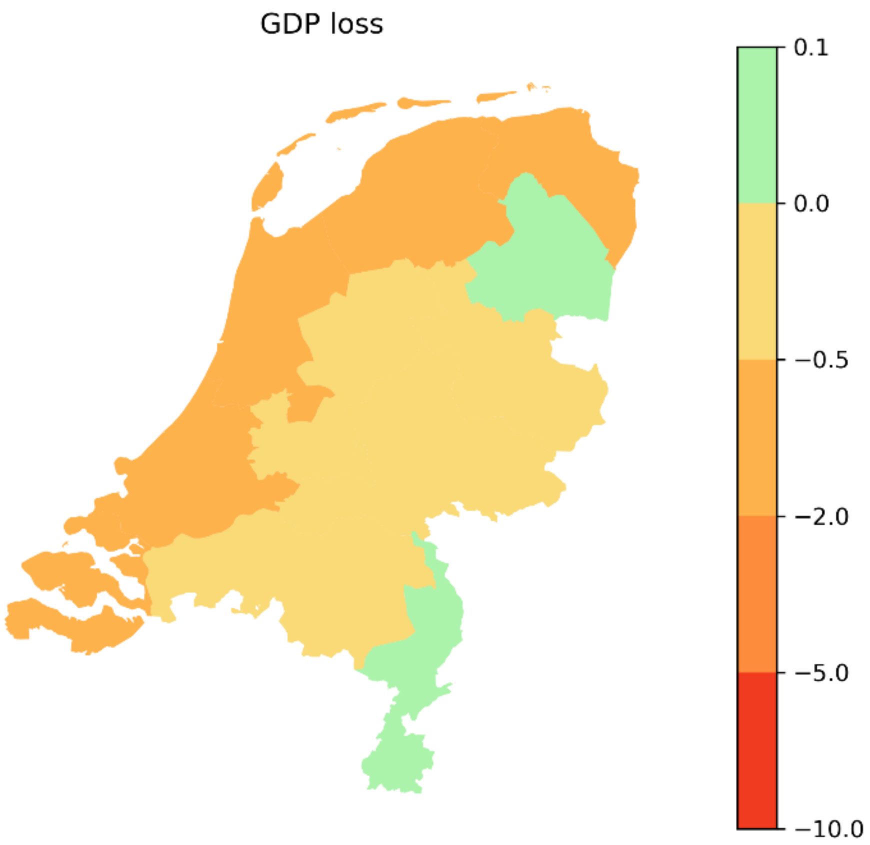
Results (I) – Regional and national GDP relative (%) change in 2100





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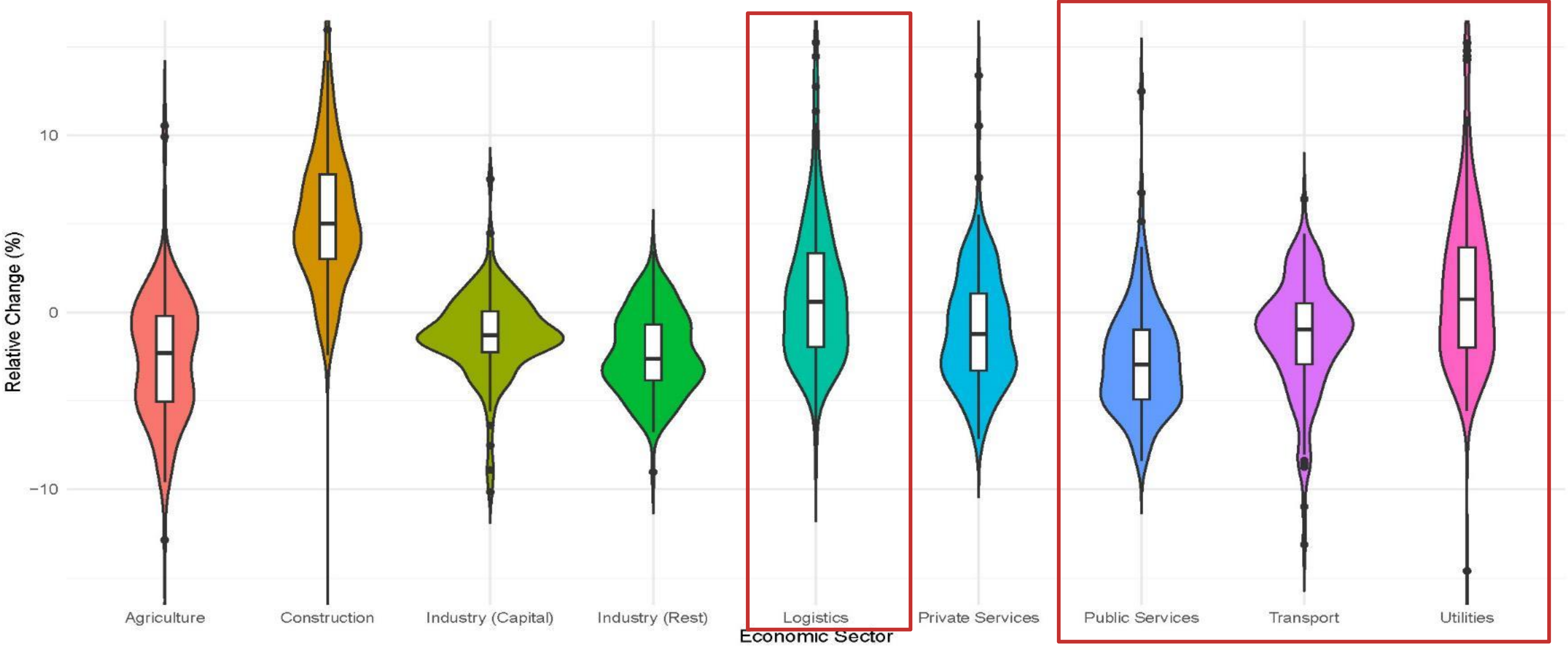
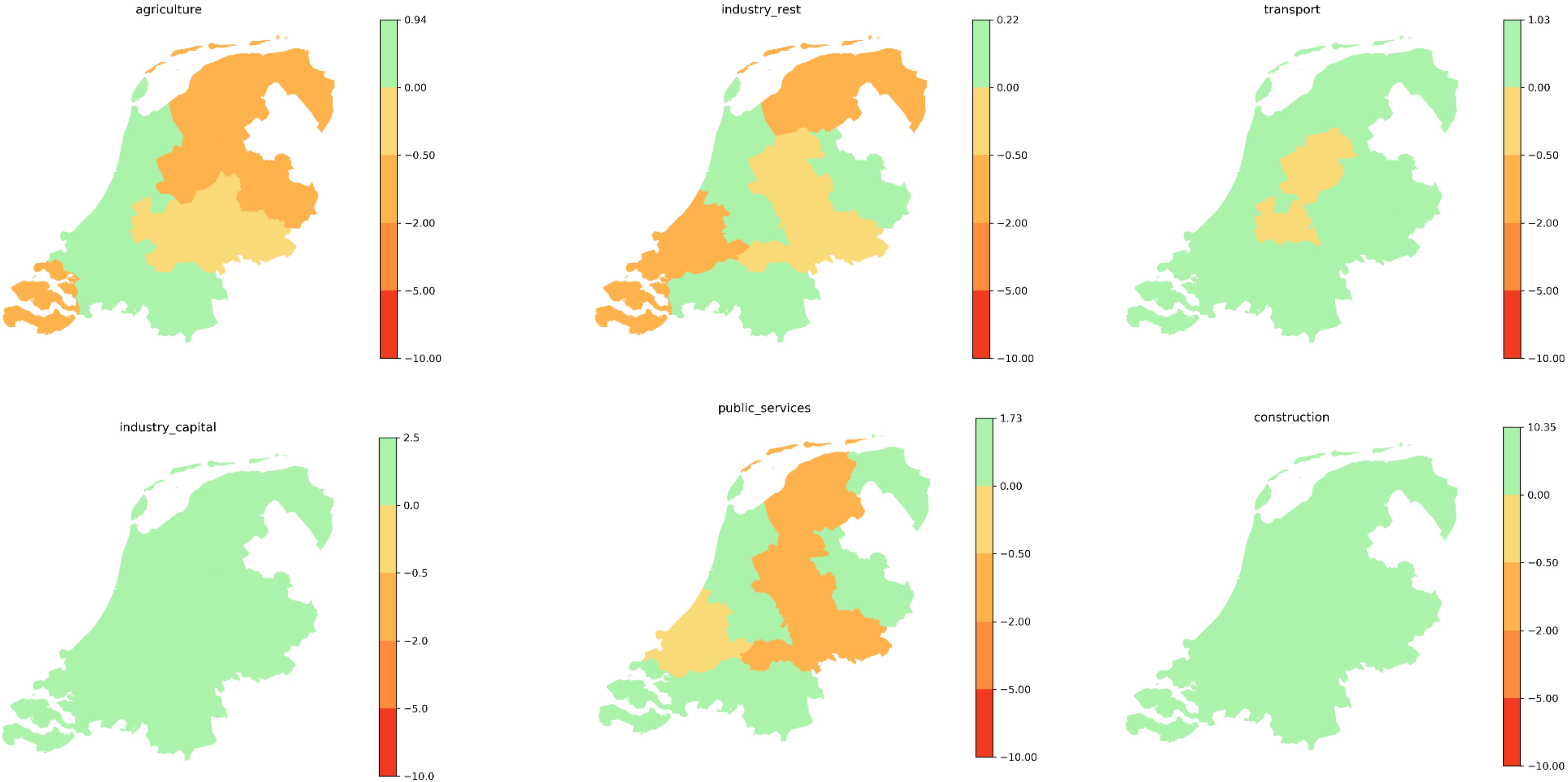
Results (II) – Sectoral value-added relative (%) change in coastal regions in 2100




agriculture
0.94
0.00
−0.50
−2.00
−5.00
−10.00
industry_rest
0.22
0.00
−0.50
−2.00
−5.00
−10.00
transport
1.03
0.00
−0.50
−2.00
−5.00
−10.00
industry_capital
2.5
0.0
−0.5
−2.0
−5.0
−10.0
public_services
1.73
0.00
−0.50
−2.00
−5.00
−10.00
construction
10.35
0.00
−0.50
−2.00
−5.00
−10.00

Implications

- By neglecting the regional and sectoral dimensions of the economy, previous assessments have underestimated the economic impact of SLR in Europe.

- Climate-induced hazards (such as SLR) can trigger indirect negative impacts and rearrange the sectoral composition of regional economies.
  - **Public Services** and **Industry** are expected to lose; **Construction** is expected to grow due to recovery efforts.
  - Policy-makers should be aware of these potential rearrangements in their planning.

- Given the diversity of impacts across regional and sectoral dimensions, tailored adaptation strategies at the regional level are of paramount importance.
  - Public investment strategies can be aligned with SLR development path.

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Food for thought…

- Mitigation is a global effort. Adaptation is local. We need to move to more granular regional assessments!
- These results do not include any tipping points or cascading effects of high SLR. Should the extremes be considered?
- What about the **public-private investment nexus** for climate change adaptation?
- Public and private adaptation; hard protection vs purely driven by market forces – business and HH can move and disinvest in capital from certain regions and sectors? Should the Overton window include retreat as a policy option in the Netherlands?

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Thank you for your attention!

Web: http://www.sc3.center/
Twitter: @sc3_team
BlueSky: @sc3team.bsky.social

Email: t.chatzivasileiadis@tudelft.nl

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Socio-economic Complexity of Climate Change

Bibliography

- Berrang-Ford, L., Siders, A. R., Lesnikowski, A., Fischer, A. P., Callaghan, M. W., Haddaway, N. R., ... & Abu, T. Z. (2021). A systematic global stocktake of evidence on human adaptation to climate change. *Nature Climate Change*, *11*(11), 989-1000.
- European Spatial Planning Observation Network (ESPON) (2021). ESPON-TITAN: Territorial Impacts of Natural Disasters. https://www.espon.eu/sites/default/files/attachments/ESPON-TITAN_Main%20Report.pdf
- Hallegatte, S. (2008). An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina. *Risk Analysis: An International Journal, 28*(3), 779-799.
- Huizinga, J., De Moel, H., & Szewczyk, W. (2017). *Global flood depth-damage functions: Methodology and the database with guidelines* (No. JRC105688). Joint Research Centre (Seville site).
- Ivanova, O., Kancs, d. & Thissen, M (2019). Eu economic modelling system. *arXiv preprint arXiv*:1912.07115.
- Lincke, D. et al. (2021) D2. 3 impacts on infrastructure, built environment, and transport. https://doi.org/10.5281/zenodo.5703656
- Pant, H. M. et al. (2015). A generic approach to investment modelling in recursive dynamic CGE models.
- Vousdoukas, M. I. et al. (2020). Economic motivation for raising coastal flood defenses in Europe. *Nat. communications 11*, 2119.

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EU-EMS – Model characteristics

- Spatial computable general equilibrium (SCGE) model built by PBL Netherlands
- The full model includes the representation of 62 countries plus ROW with 60 economic sectors
- Using a 2013 database, the model has detailed regional dimensionality for EU28 countries with 271 NUTS2 regions
- The database for the model was constructed by PBL Netherlands and includes a detailed MRIO table for the world
- The sectoral and geographical levels of aggregation are flexible
- The model is recursive dynamic, involving capital accumulation and technology progress, which link the temporal equilibria at every time step
    - For our application, the model runs in time steps of 5 years, from 2015 to 2100

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Impact of critical infrastructure intervention

Region	NUTS2 code	2050	2070	2100
Cheshire	**UKD6**	-0.10%	-0.20%	-1.10%
Merseyside	**UKD7**	-0.10%	-0.20%	-1.00%
Provincia Autonoma di Trento	**ITH2**	-0.10%	-0.20%	-0.80%
Provincia Autonoma di Bolzano-Bozen	**ITH1**	0.00%	-0.20%	-0.80%
Pomorskie	**PL63**	0.00%	-0.10%	-0.80%
Guadeloupe	**FR91**	0.00%	-0.10%	-0.70%
Friuli-Venezia Giulia	**ITH4**	0.00%	-0.10%	-0.70%
Martinique	**FR92**	0.00%	-0.10%	-0.70%
Zachodniopomorskie	**PL42**	0.00%	-0.20%	-0.70%
Umbria	**ITI2**	0.00%	-0.10%	-0.60%
Basilicata	**ITF5**	0.10%	0.30%	1.40%
Eastern Scotland	**UKM2**	0.00%	0.10%	1.50%
Hampshire and Isle of Wight	**UKJ3**	0.00%	0.00%	1.80%
Devon	**UKK4**	0.00%	0.00%	2.20%
Prov. West-Vlaanderen	**BE25**	0.00%	0.00%	2.30%
Kent	**UKJ4**	0.00%	0.40%	3.30%
Bremen	**DE50**	0.70%	1.30%	4.00%
Weser-Ems	**DE94**	0.70%	1.30%	7.10%
East Yorkshire and Northern Lincolnshire	**UKE1**	0.00%	2.00%	12.10%
Lincolnshire	**UKF3**	3.00%	7.20%	20.10%
Aggregate GDP	**EU&UK**	0.00%	-0.01%	-0.06%

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Methods: Asset-based distribution of direct damages

- **Direct economic damages to European regions from SLR** at the NUTS2 level are available openly through the COACCH project (Lincke et al., 2021) in 5-year steps.

- But, <u>how do we distribute them across sectors</u>? We can use the **ESPON-TITAN database** (ESPON, 2023).
  - By considering 155 different flooding events between 1995 and 2016, they constructed damage distribution matrices (DDM) for the affected NUTS3 regions, splitting the costs into 5 broad categories (**Residential**, **Commercial**, **Industry**, **Transport & Infrastructure**, **Arable Land**).
  - The DDMs were constructed using the JRC's Risk Data Hub data and European depth-damage functions (Huizinga et al., 2017).

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Methods: Mapping assets to sectors

- We can now associate the asset type to a sector, further splitting the original total damage based on the relative size of the sector by capital stock in the asset type.
- Since the model does not currently feature a housing stock, the consumption of households is hit directly, forcing expenditure in reconstruction (i.e., benefitting the **Construction** sector).

Asset class	Sector(s)
Arable Land	Agriculture
Commercial	Construction, Private Services, Public Services
Industry	Industry (Capital), Industry (Rest)
Transport & Infrastructure	Utilities, Transport, Logistics
Residential	*Impacts household consumption directly

- Final direct damage per region-sector: $DD_{i,r} = TDD_r \times sh(TDD_r)_a \times \frac{K_{s,i,r}}{\sum_{j\in a} K_{s,j,r}}$
- Modified capital accumulation function: $K_{s,i,r,t+1} = K_{s,i,r,t}\left(1 - \left(\delta + \boxed{\frac{DD_{i,r}}{K_{s,i,r}}}\right)\right) + I_{i,r,t}$

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