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Assessment, benchmarking and stress-testing resilience of critical infrastructures: A novel, indicator-based approach developed in the EU project SmartResilience

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Abstract

The contribution highlights the practical/implementation aspects of new EU project SmartResilience and its application in terms of resilience assessment, resilience benchmarking and stress-testing. The project is fully aware of the limitations and pitfalls of quantitative approaches when assessing complex, time-dependent issues such as resilience of critical infrastructures. The project proposes to rely on the concept of "resilience matrix", redefined in such a way that it encompasses also the early (e.g. emerging risks related considerations), on one side, and the final process of learning and adaptation on the other side, i.e. other wend of the resilience cycle. In particular, the project looks also at the aspects related to the fact that modern critical infrastructures are becoming increasingly "smarter" and that this "making the infrastructures smarter" usually means making them smarter in normal operation and use. This is, however, an issue to be verified, if smart critical infrastructures will behave "smartly" and be "smartly resilient" also when exposed to extreme threats, especially the new one such as extreme weather disasters or, e.g., terrorist attacks. The paper focusses onto two main issues. The first being the indicator-based approach which comprises the identification of existing indicators suitable for assessing resilience of SCIs, identification of the new "smart" resilience indicators including those from Big Data, development of the new advanced resilience assessment methodology based on smart RIs ("resilience indicators cube", including the resilience matrix). The second one is the application of the methodology and the approach developed in the project, onto eight case studies in Europe. Beside the resilience assessment, the approach and the methodology are intended to be applied for benchmarking and stress-testing, in the later stages of the project.

Acknowledgments

The paper is based on the Grant Agreement No. 700621 supporting the work on the SmartResilience project provided by the Research Executive Agency (REA) ('the Agency'), under the power delegated by the European Commission ('the Commission'). This support is gladly acknowledged here, as well as the collaboration of all the partners and their representatives (persons) involved.

SMART RESILIENCE

Smart Resilience Indicators for Smart

Assessment, benchmarking and stress-testing resilience of critical infrastructures:

A novel, indicator-based approach developed in the EU project SmartResilience

CIPRE Conference, Den Haag 2017

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Abstract - keywords

- Dependencies > interdependencies > stress testing (in critical infrastructures)
- Framework:
  a. Characteristics: upstream, internal, downstream
  b. Classes: physical, cyber, geographic, and logical
  c. Dimensions: operating environment, coupling and response behavior, type of failure, infrastructure characteristics, and state of operations
- "Smart" Critical Infrastructures (the SmartResilience project)
- Practical Method
- (expected) Results / Applications

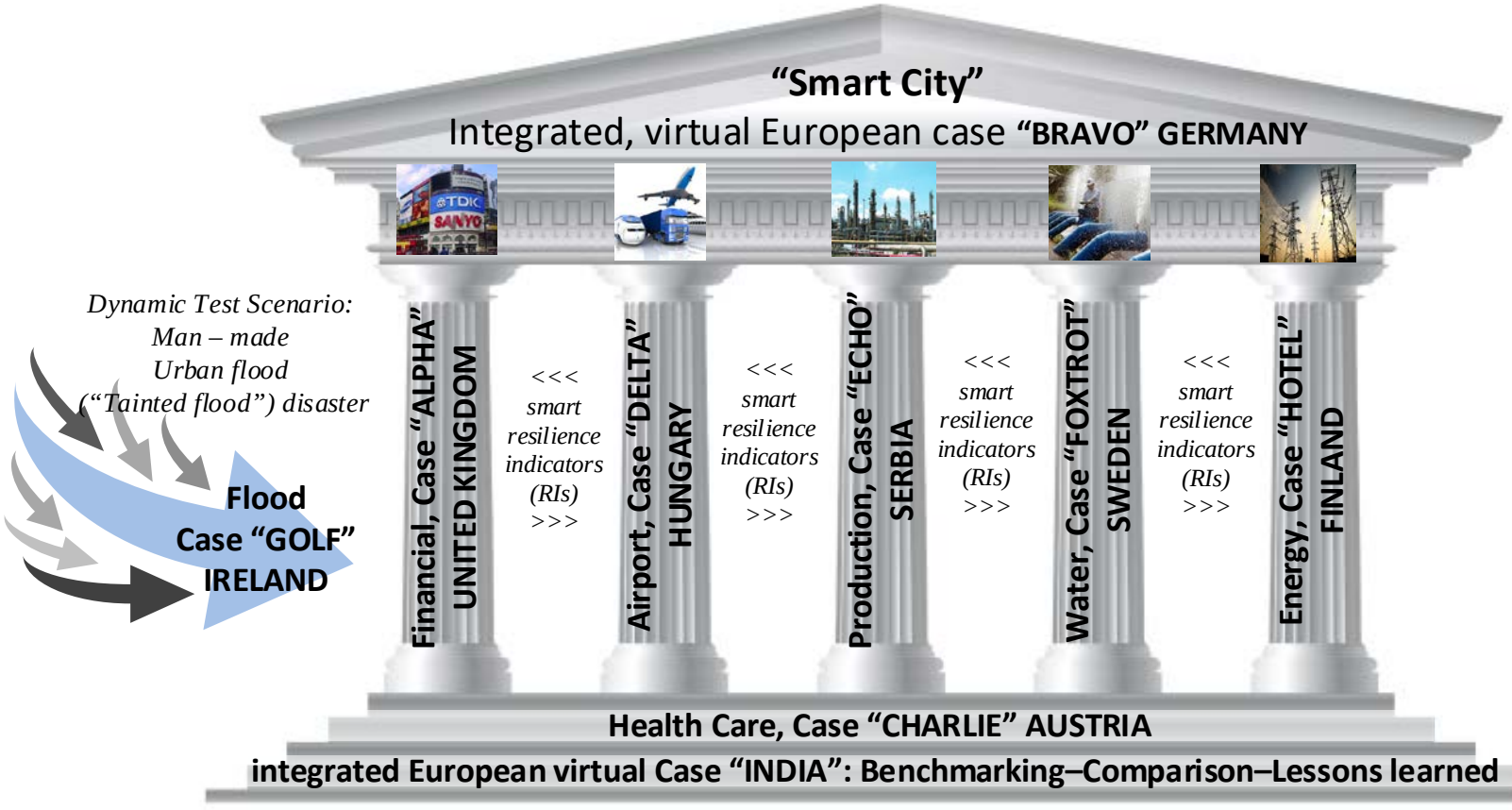
SMART RESILIENCE

Smart Resilience Indicators for Smart Critical Infrastructures

“Smart” Critical Infrastructures

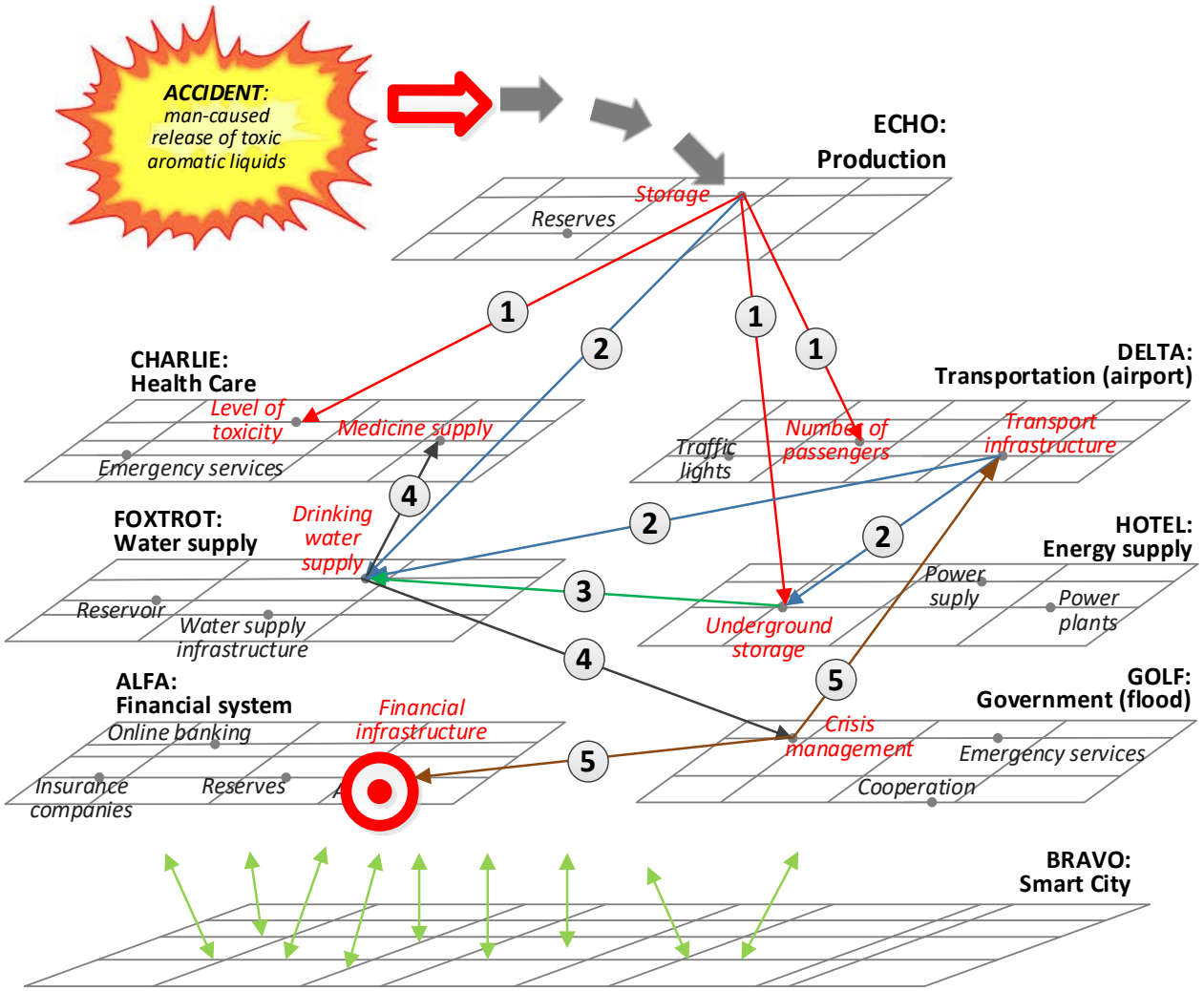
(the SmartResilience project)

Smart Critical Infrastructures
(in SmartResilience project)



Interdependencies > Stress testing

Map the safety/security landscape… (the SmartResilience project example)



SYSTEMIC RISKS

Safety

Safety

Security

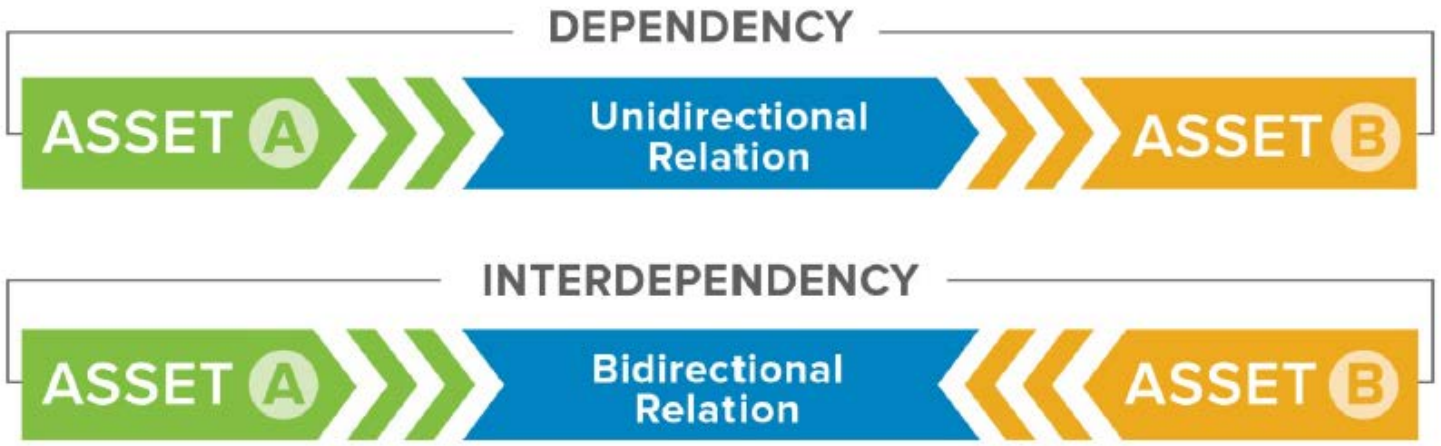
Safety

Security

Safety

Security

Dependencies > interdependencies > systemic risks (in critical infrastructures)



SMART RESILIENCE

Smart Resilience Indicators for Smart Critical Infrastructures

The Framework:

Characteristics:

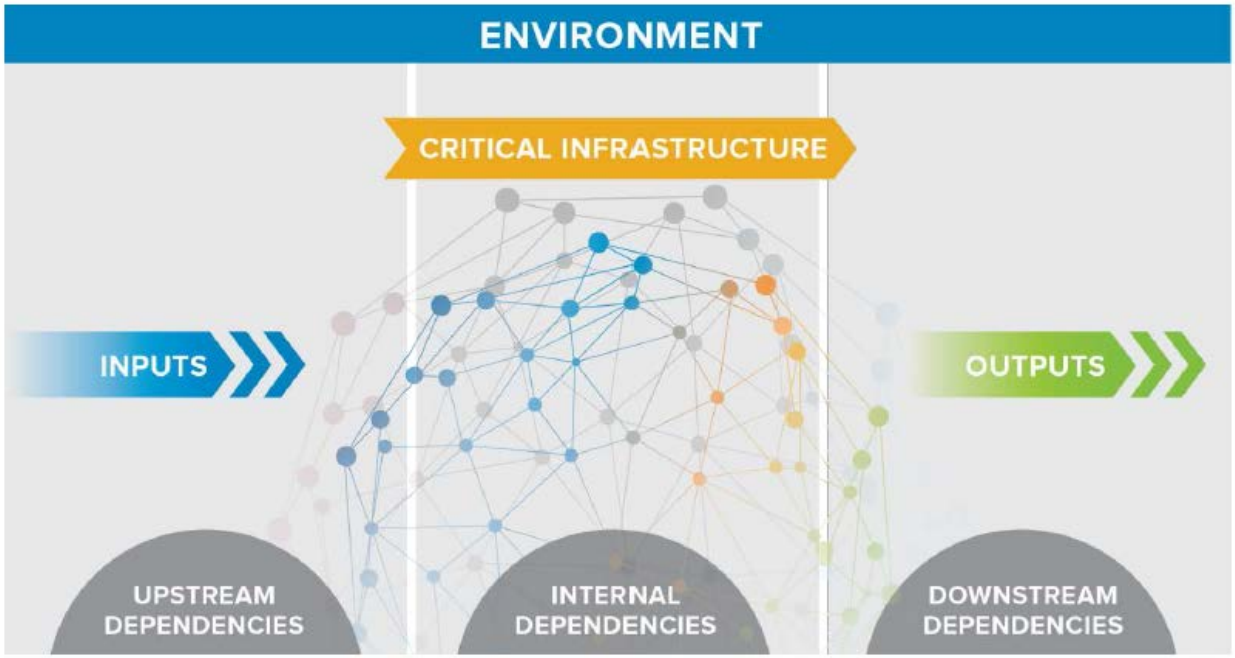
upstream, internal, downstream

Classes:

physical, cyber, geographic, and logical

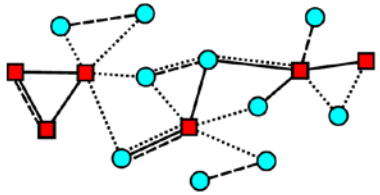
Dimensions:

operating environment, coupling and response behavior, type of failure, infrastructure characteristics, and state of operations



Stress-testing: resilience of interdependent infrastructure (systems)?

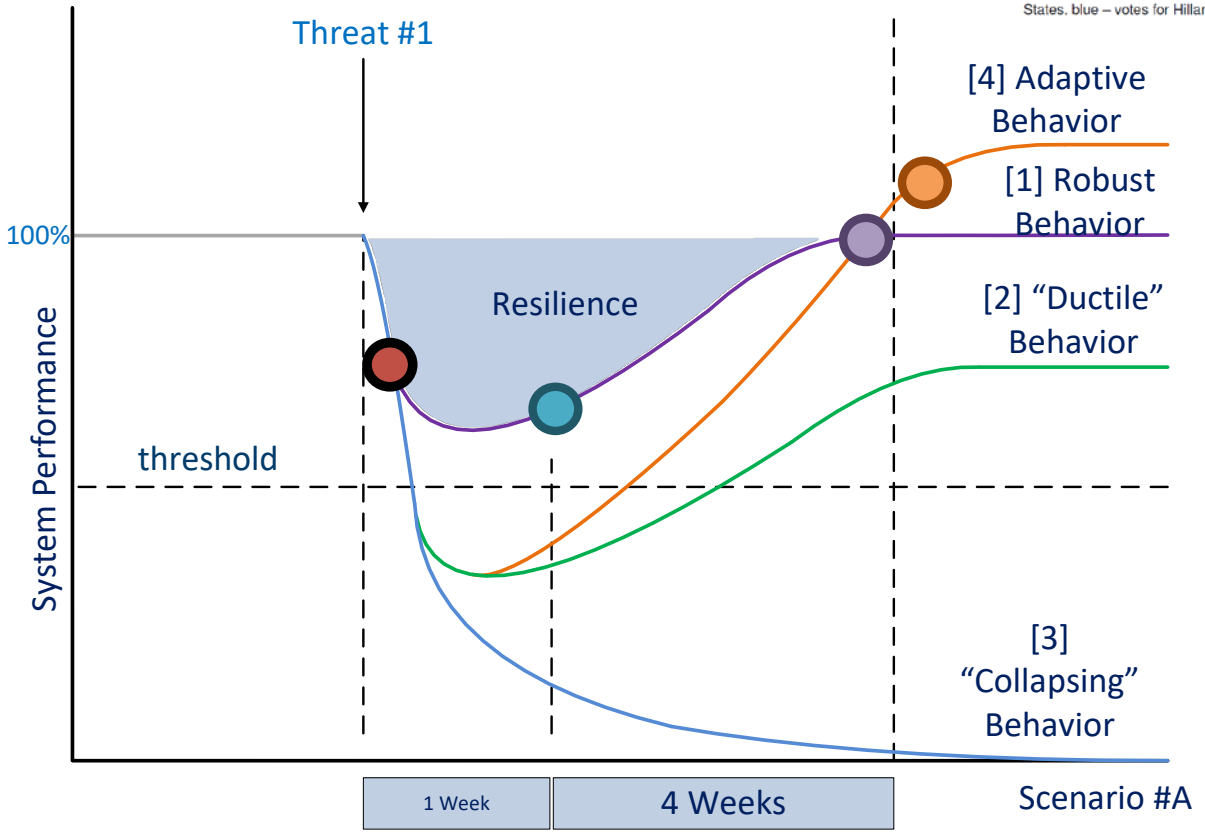
A multiplex network is a collection of networks on the same set of nodes



Links. $\alpha = 1$: communication: full line; $\alpha = 2$: trading: dashed line; $\alpha = 3$: friendship: dotted line.

States. blue – votes for Hillary; red – votes for Trump.

Thurner, Hanle, Klimek et al. 2016



No. of other dept./plants affected

50% capacity recovered in 1 week

100% capacity recovered in 4 weeks

Improved protection control system in 3 months for passengers

Acatech, Recil-Tech, 2016

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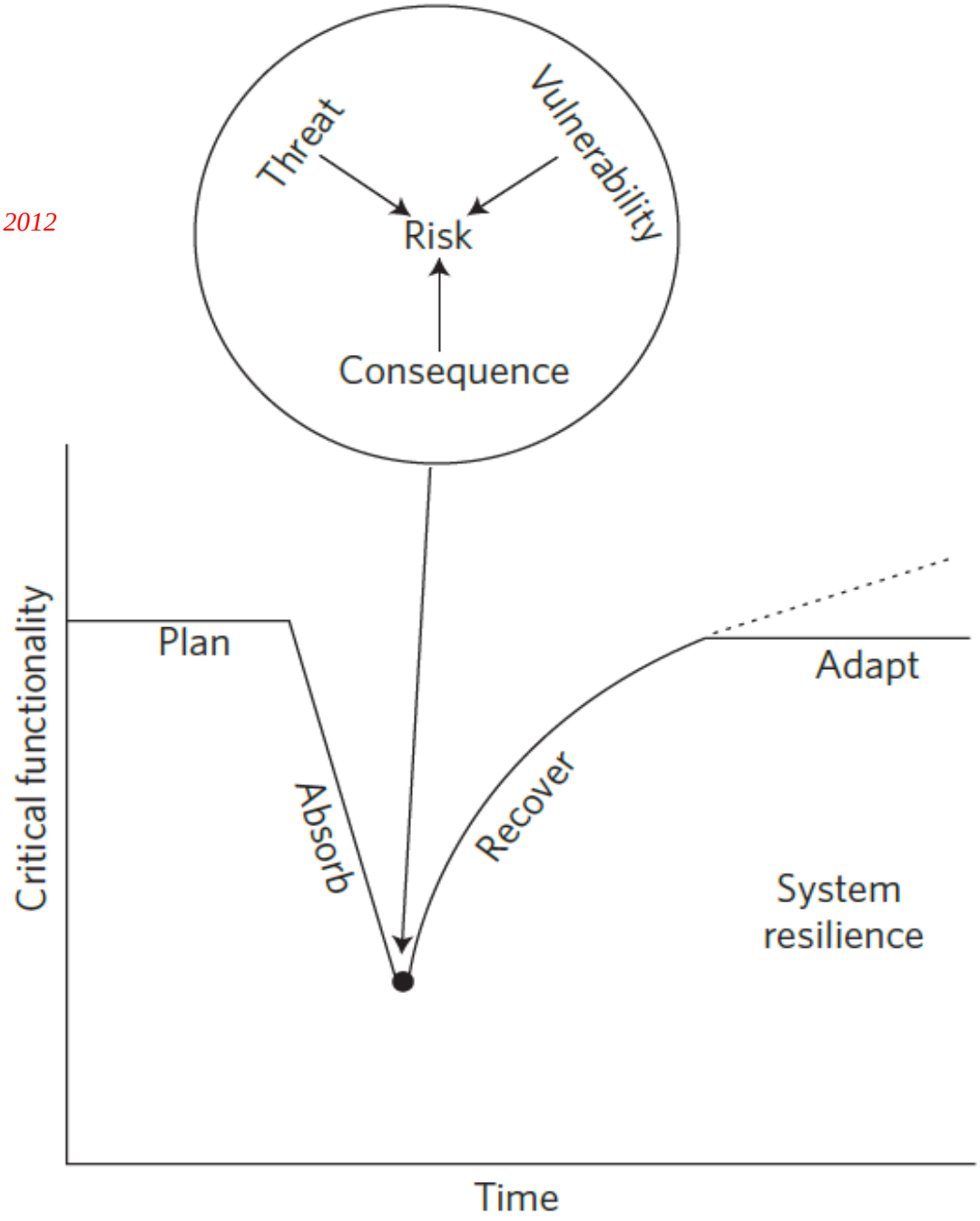
Practical Method

Conventional Indicators

What when the "risk happens"?

Linkov et al. 2014, ANL 2012



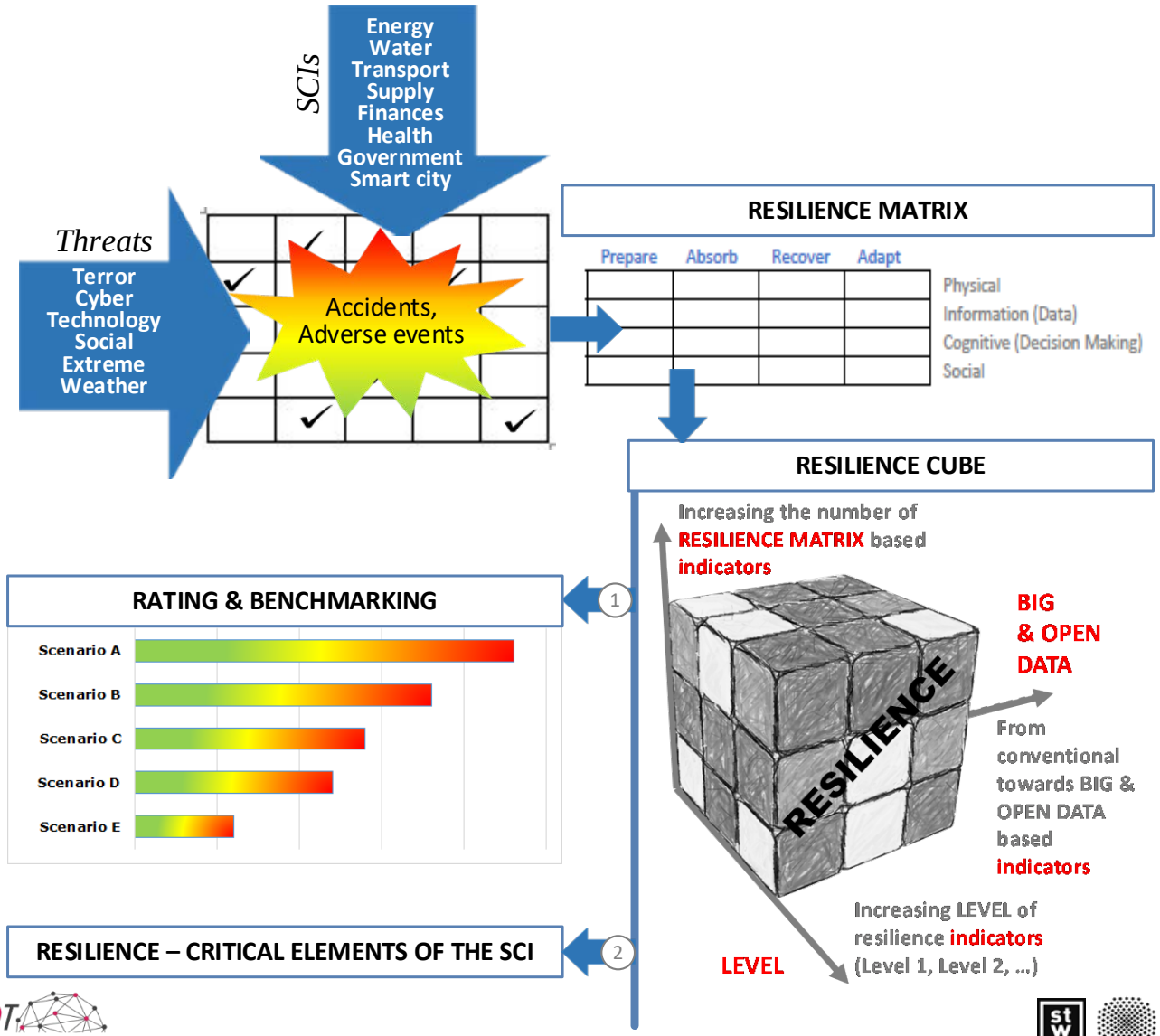
SMART RESILIENCE

Resilience matrix

Dimensions" of the Resilience		
Linkov Error! Reference source not found. 4 dimensions	**T1.2: 5 dimensions**	**Comments**
1. Physical	1. System / physical	Includes technological aspects of the given infrastructure, as well as the physical/technical networks being part of a given infrastructure, interconnectedness with other infrastructures and systems
	2. Information / data	Includes also the technical systems dealing with information/data
2. Information (Data)	3. Organizational / business	Includes business-related aspects, financial and HR aspects as well as different types of respective organizational networks
3. Cognitive (Decision Making)	4. Societal / political	Includes the broader societal and social context, also stakeholders not directly involved in the operation and/or social networks)
4. Social	5. Cognitive / decision-making	Includes the perception aspects (e.g. per vulnerabilities)

Phases →→→ vs. Dimensions ↓↓↓	1. Understand risks	2. Anticipate / prepare	3. Absorb / withstand	4. Respond / recover	5. Adapt / learn
1. System / physical					
2. Information / data		5×5			
3. Organizational / business					
4. Societal / political					
5. Cognitive / decision-making					

Resilience cube in the context



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Example

Make sure that risk awareness is maintained (avoid underestimation of risk)

CSF 1: Risk Awareness

Understand – anticipate – and monitor

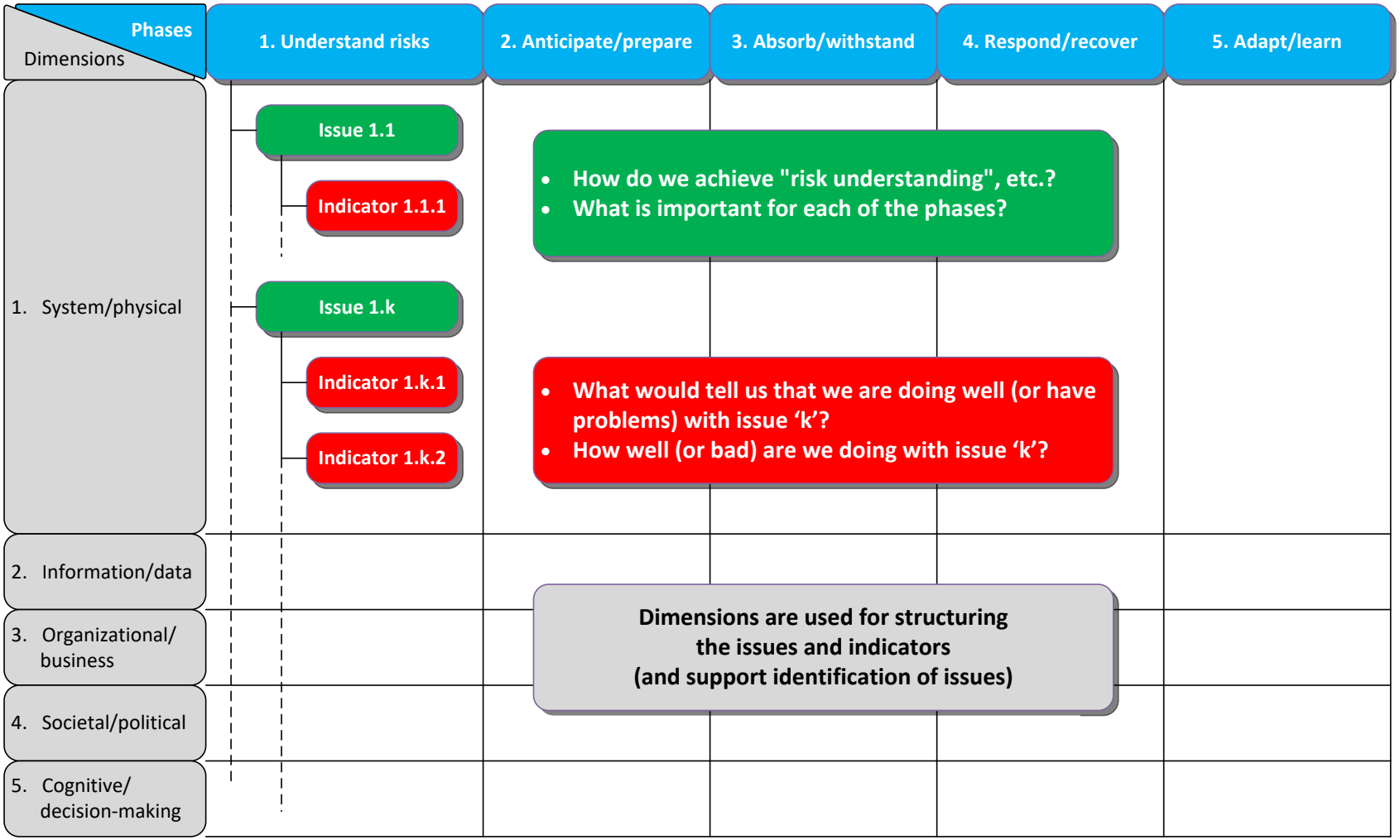
How do we achieve knowledge and experience about risk/hazards?

What can we expect?

- Risk under-standing 1.1
  - 1.1.1 System knowledge
  - 1.1.2 Information about risk through e.g. courses & doc. (Hazop, QRA, ...)
  - 1.1.3 Reporting of incidents, near-misses and accidents
  - 1.1.4 Information about the quality of barriers (technical safety)
- Anticipation 1.2
  - 1.2.1 Risk/hazard identification (Hazid, …)
  - 1.2.2 Learn from own experiences & accidents
  - 1.2.3 Learn from other's experiences & accidents

What is anticipation?
How do we know what to expect?

Resilience Matrix: Phases/dimensions + issues & indicators

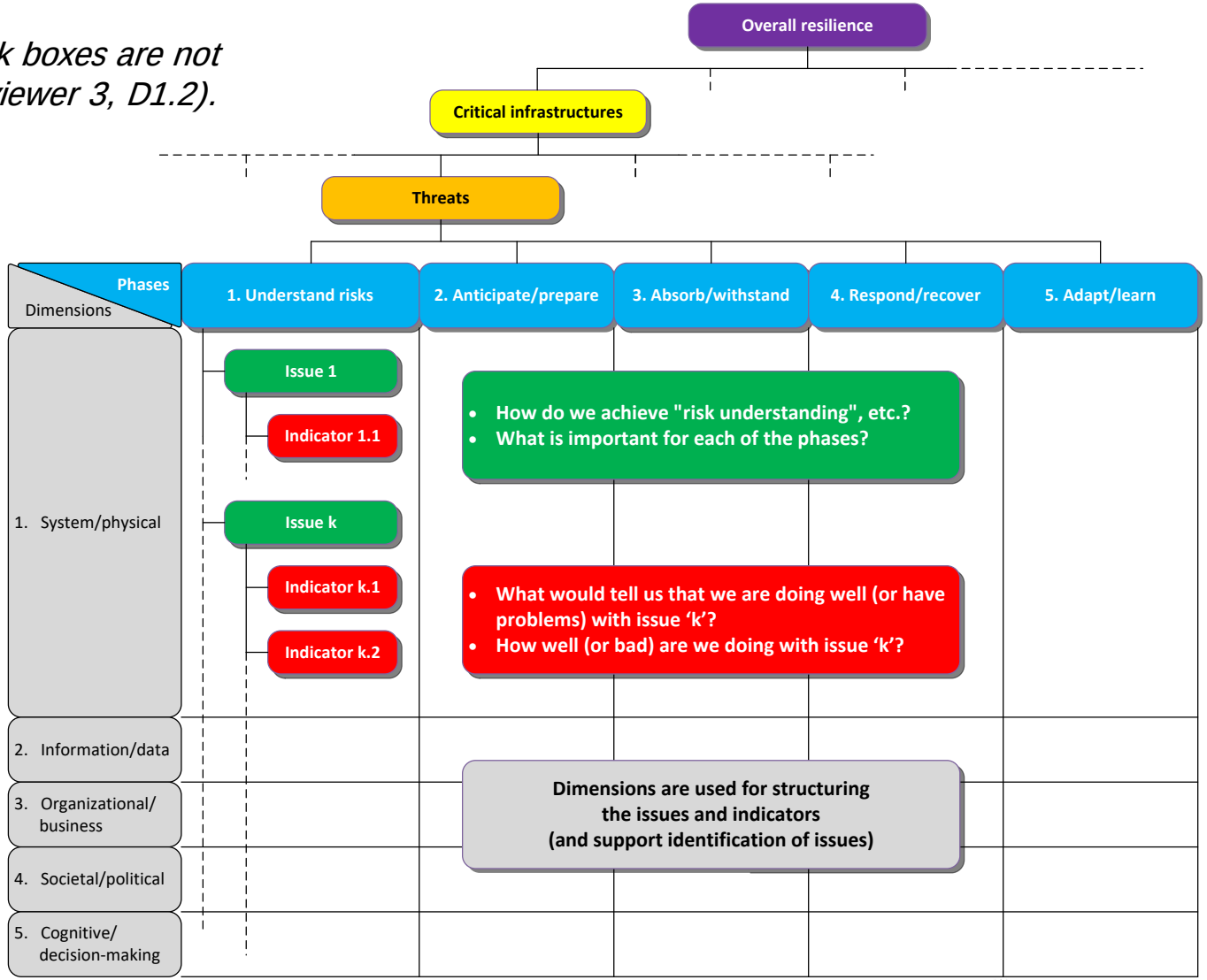


Phases/(dimensions) – Issues – Indicators

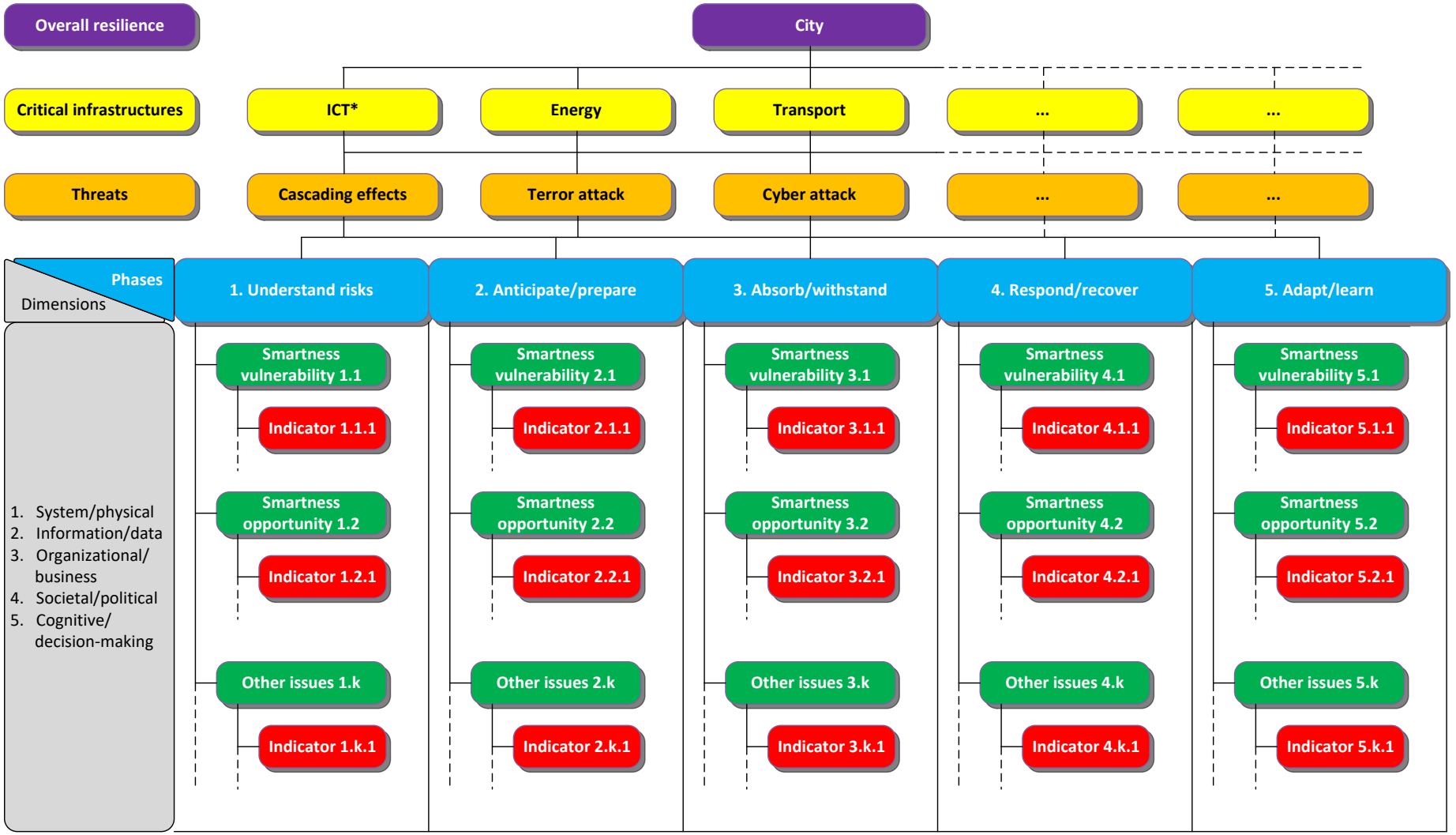
Outline of assessment methodology

Simple, transparent and easily understood ...

"Smart black boxes are not smart" (Reviewer 3, D1.2).



ICT, Cascading effects & Smartness: NOT ONLY infrastructures are interdependent… also threats!



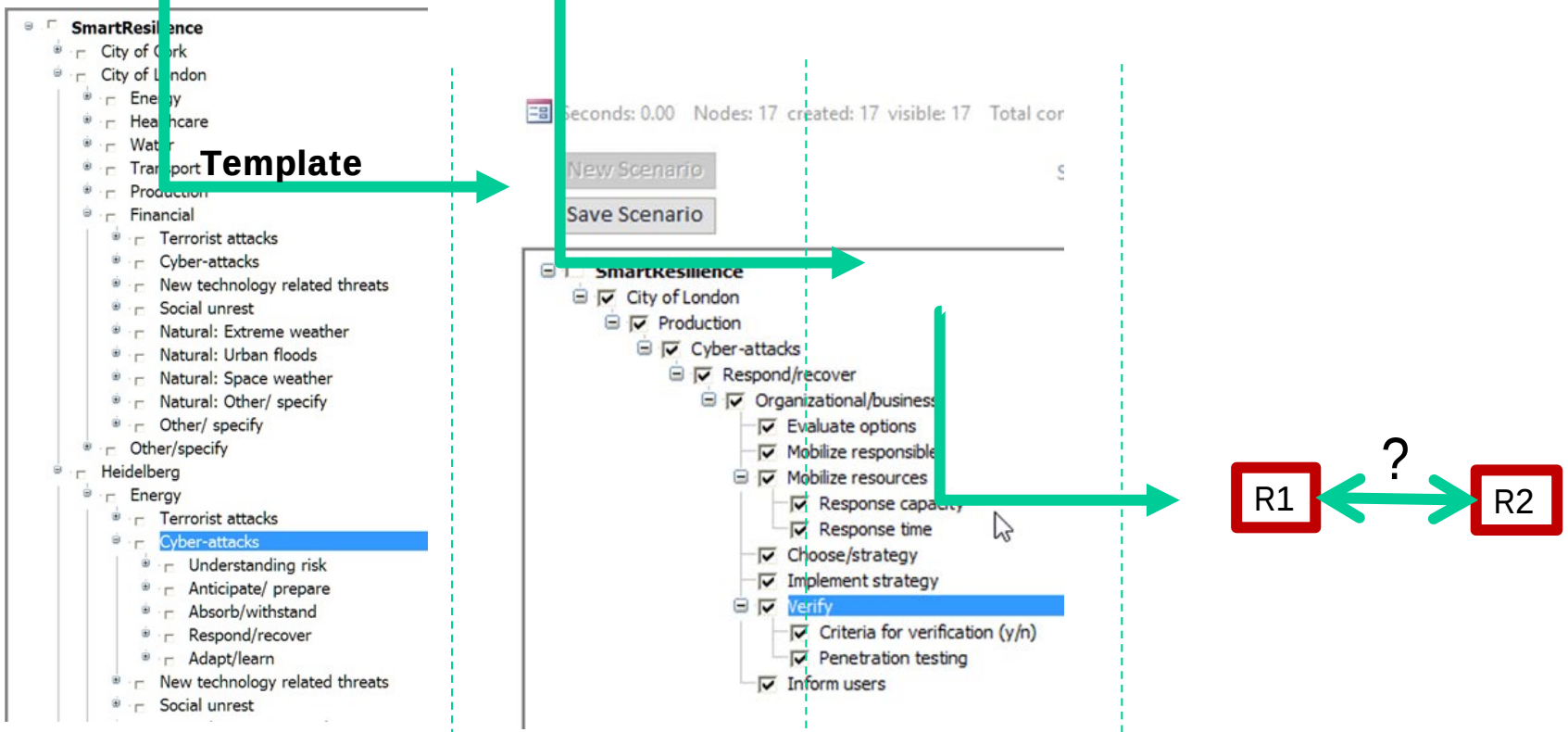
* ICT has an overarching role, affecting other CIs

Proposed SmartResilience method steps

1. Select the area, e.g. a smart city – *Level 1*
2. Select the relevant critical infrastructures (CIs) – *Level 2*
3. Select relevant threats for each CI, i.e. define the "scenario" – *Level 3*
4. Consider each phase (in the resilience matrix) for each threat – *Level 4*
5. Define the issues within each phase (structured/categorized according to the dimensions in the resilience matrix) – *Level 5*
6. Search for the appropriate indicators for each issue – *Level 6*
7. Determine best and worst values for each indicator
8. Assign real values to the indicators
9. Run the calculation and save the "assessment"
10. Use results/compare: (a) to previous assessment ("trend"), (b) to other assessments ("benchmarking"), or (c) to set criteria ("stress test")

Run calculations in database, save and use results

1. Define scenario **2. Use scenario** **3. Save results report** **4. Compare / benchmark**



Stress-test definition | Stress-test! | Stress-test report | R_{ST} ? Criteria

Big Data Indicators

From Big Data to interconnectedness indicators

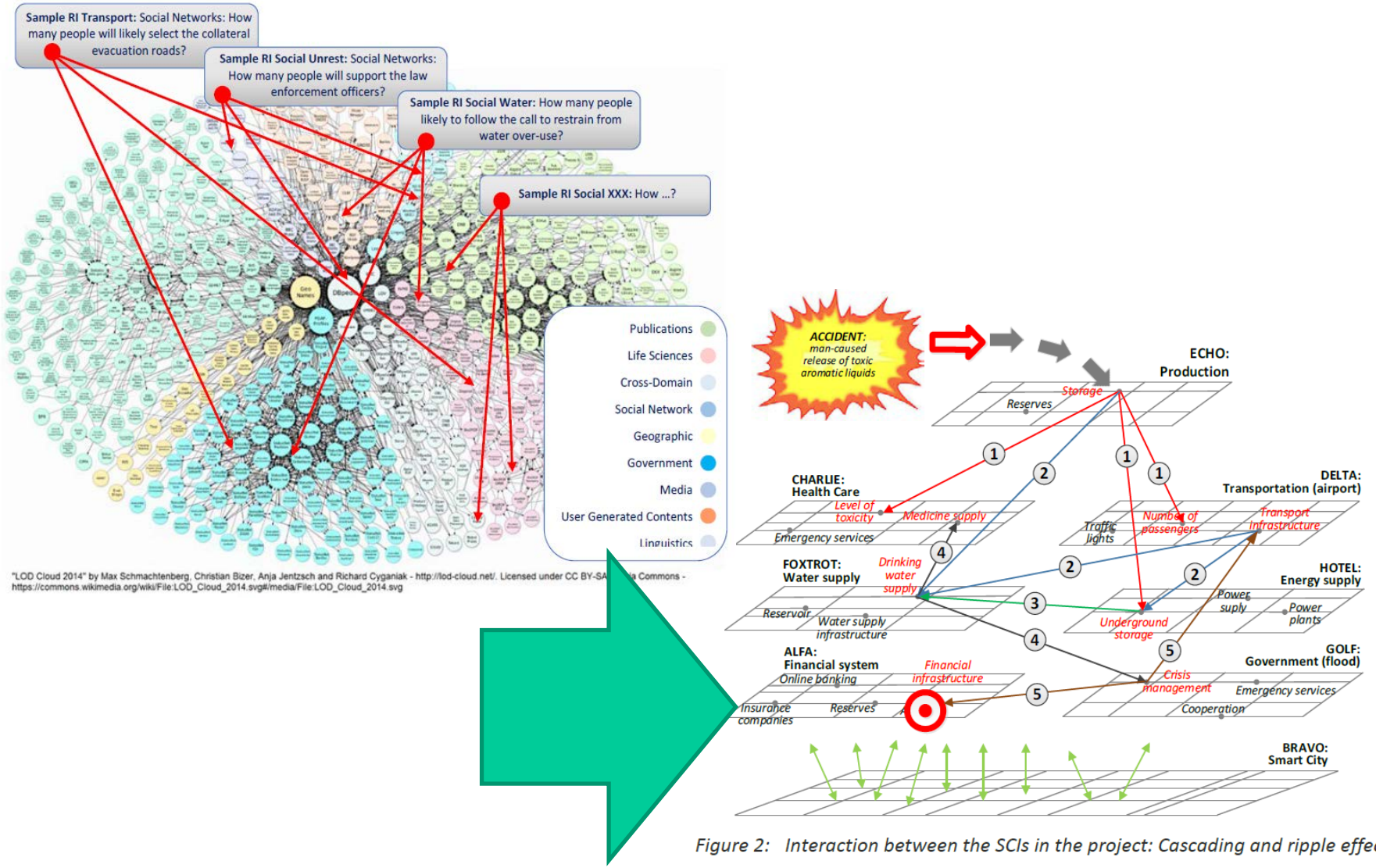


Figure 2: Interaction between the SCIs in the project: Cascading and ripple effects

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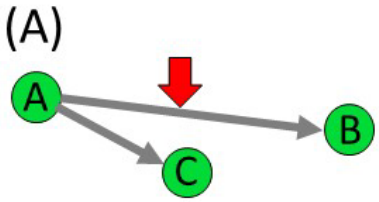
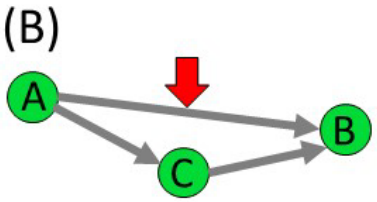
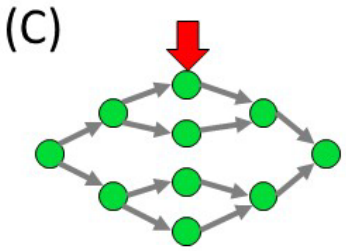
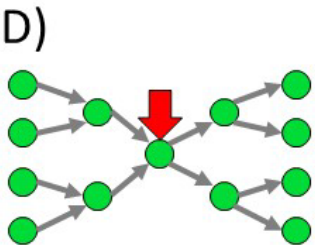
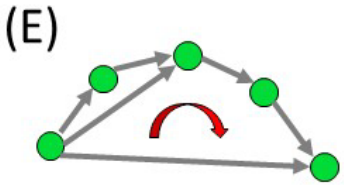
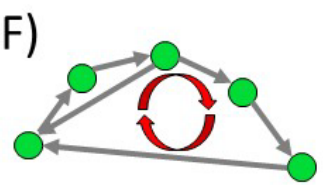
Examples of measures: Centrality, betweenness, Katz

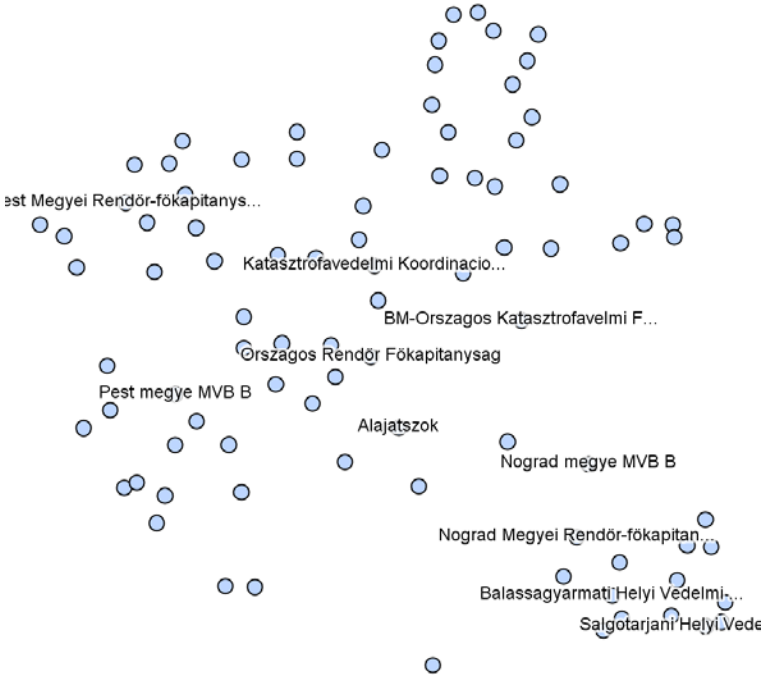
1. degree centrality
2. betweenness centrality
3. closeness centrality,
4. eigenvector centrality (Bonacich 1972)
5. Bonacich power centrality (Bonacich 1987),
6. flow betweenness centrality (Freeman 1991)
7. fragmentation centrality (Borgatti 2006),
8. reach centrality (Scholtes et al. 2016)
9. proximal betweenness (Borgatti et al. 2013),
10. mutual information (Jin et al. 2012)
11. local clustering coefficient (Jin et al. 2012)
12. modularity centrality (Newman 2004)
13. Katz prestige

Indicator development

Measure	***Low***	***High***
Resilience *Clustering Coefficient*		
Vulnerability *Betweenness Centrality*		
Efficiency *Principal Eigenvalue, Katz Prestige*		

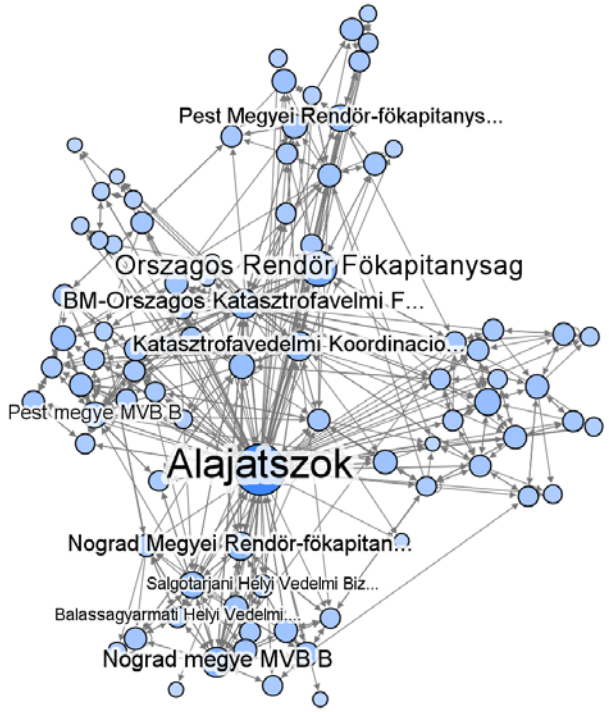
Example: Communication network

Network 1

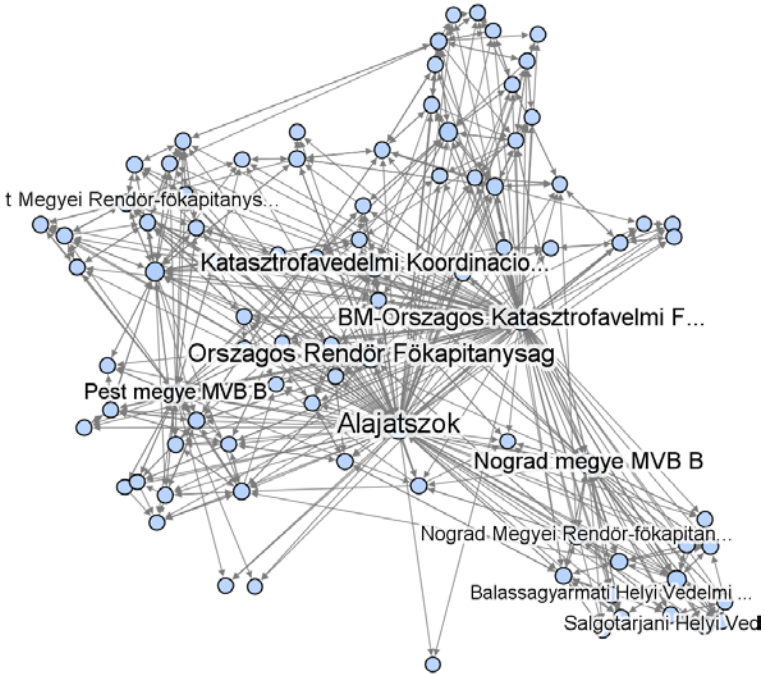


Network 2

Communication network - Summary



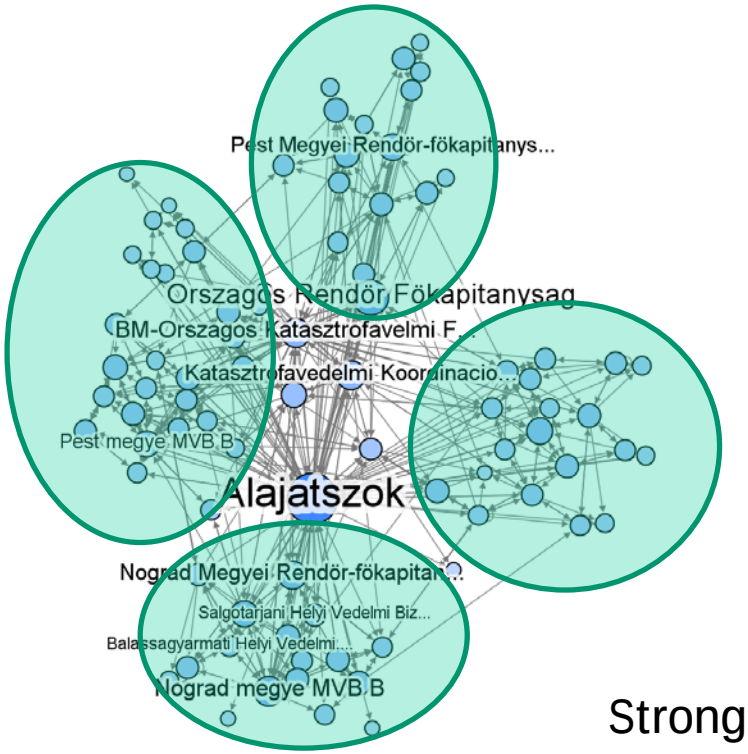
Day 1



Day 2

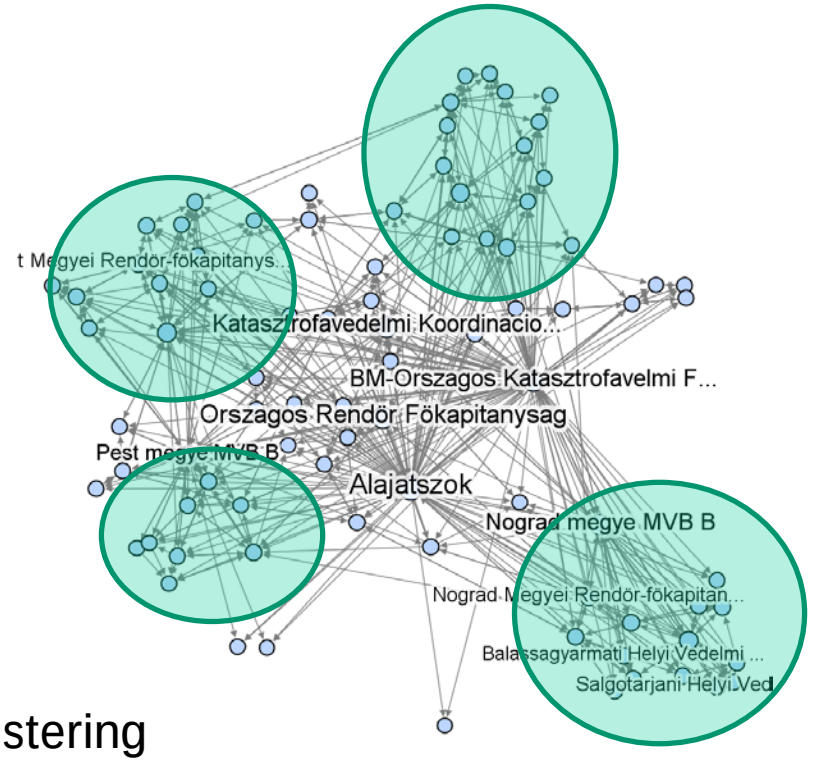
Communication network - Clusters

Participants briefed for events



Day 1

Participants *not* briefed

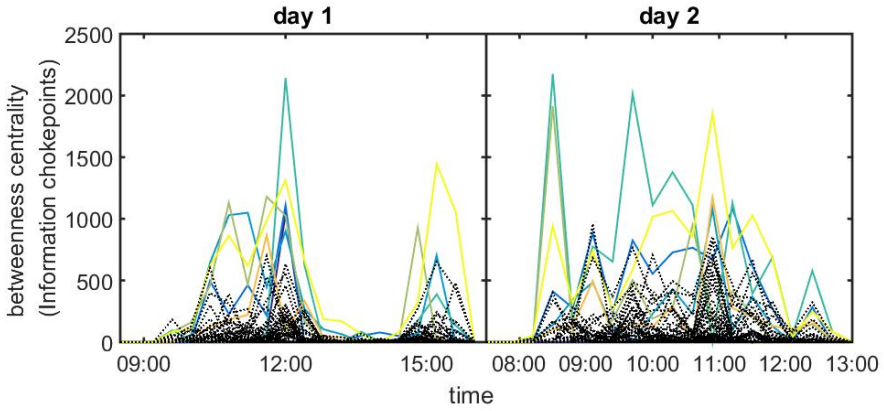


Day 2

Stronger clustering on day 1 than on day 2

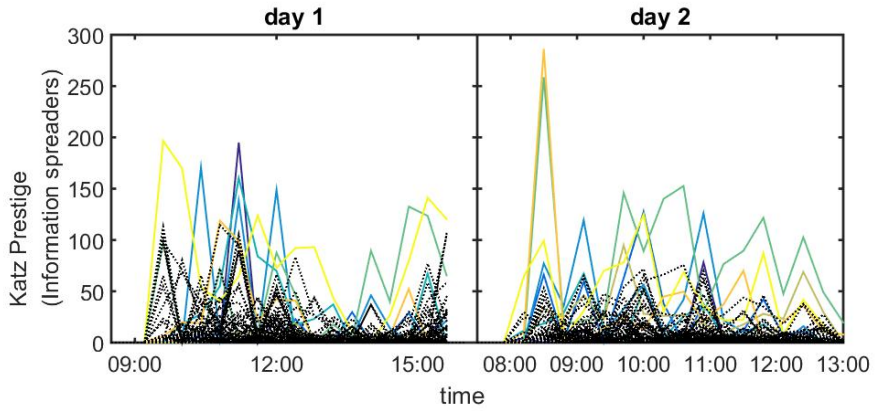
Proposed Resilience Indicators

Betweenness centrality



Salgótarjáni Helyi Védelmi Bizottság B
Nógrád megye MVB B
Nógrád Megyei Rendőr-főkapitányság B
Katasztrófavédelmi Koordinációs Tárcaközi Bizottság Nemzeti Vészhelyzet-kezelő Központ
BM-Országos Katasztrófavélmi Főigazgatóság
Pest Megyei Rendőr-főkapitányság A
Országos Rendőr Főkapitányság

Katz prestige



Balassagyarmati Helyi Védelmi Bizottság B
Pest megye MVB B
Nógrád megye MVB B
Nógrád Megyei Rendőr-főkapitányság B
Katasztrófavédelmi Koordinációs Tárcaközi Bizottság Nemzeti Vészhelyzet-kezelő Központ
Pest megye MVB A
BM-Országos Katasztrófavélmi Főigazgatóság
Országos Rendőr Főkapitányság

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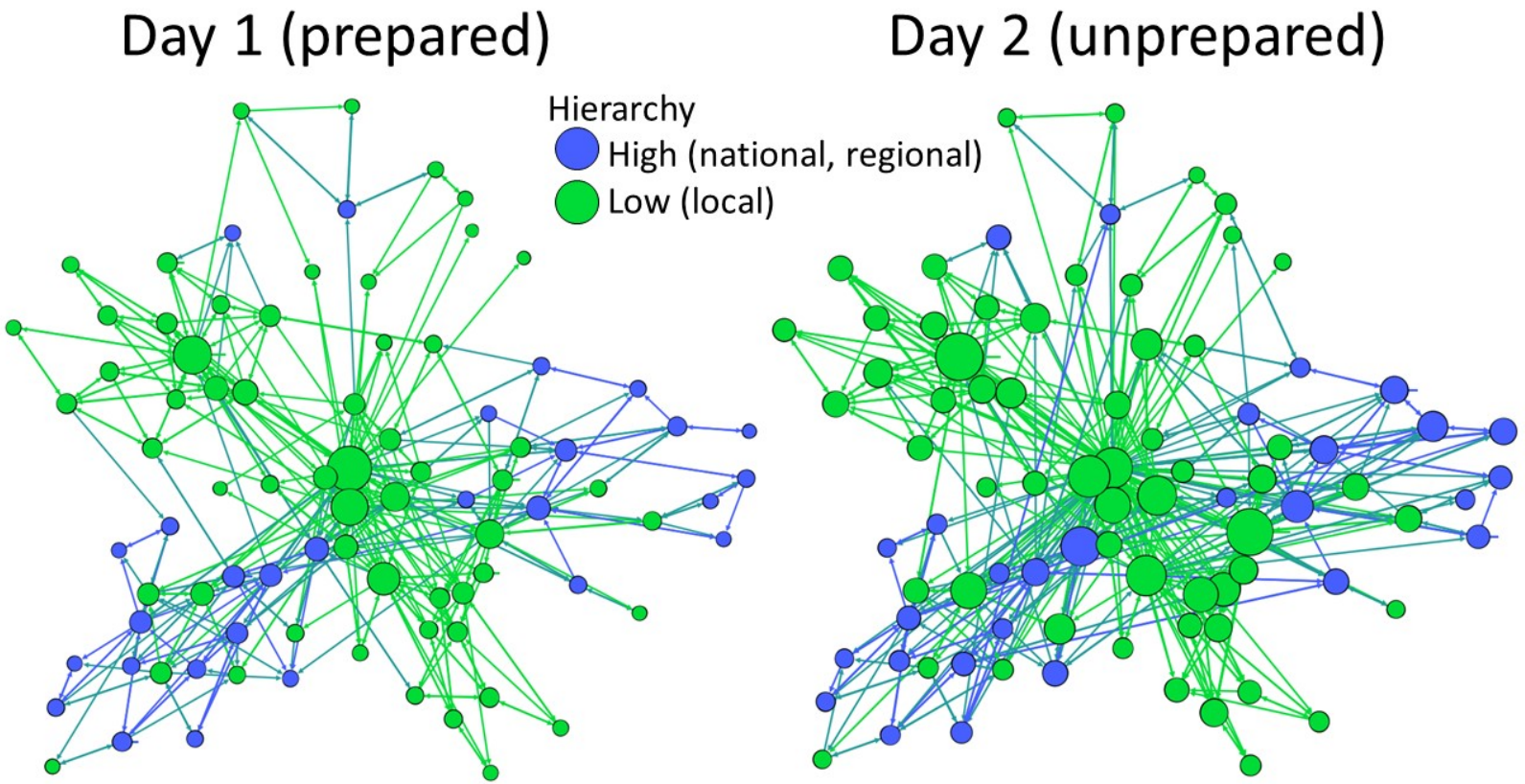
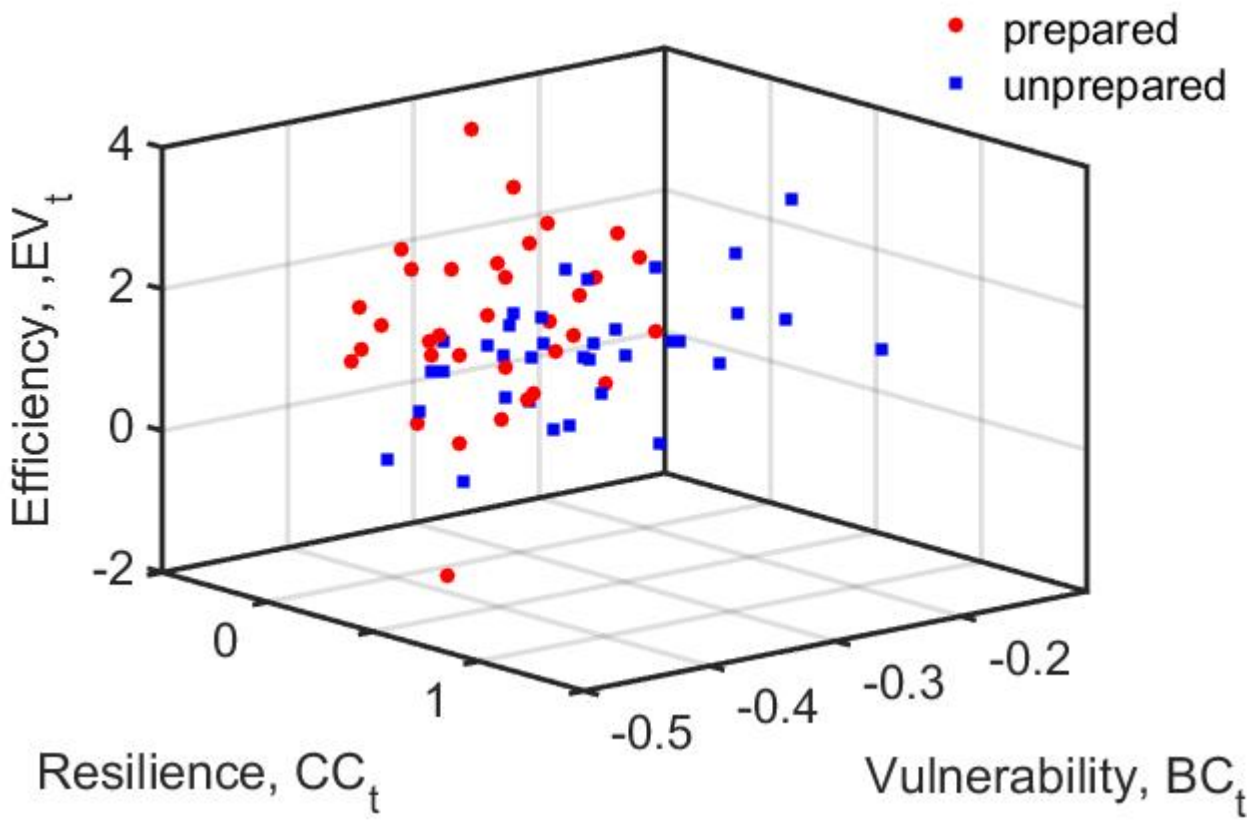
Communication networks



Each circle represents an organization, each connection (link) an information flow between the two organizations

Results – Validation of the indicators



Each point is a disruptive events with participants being either prepared (red) or unprepared (blue)

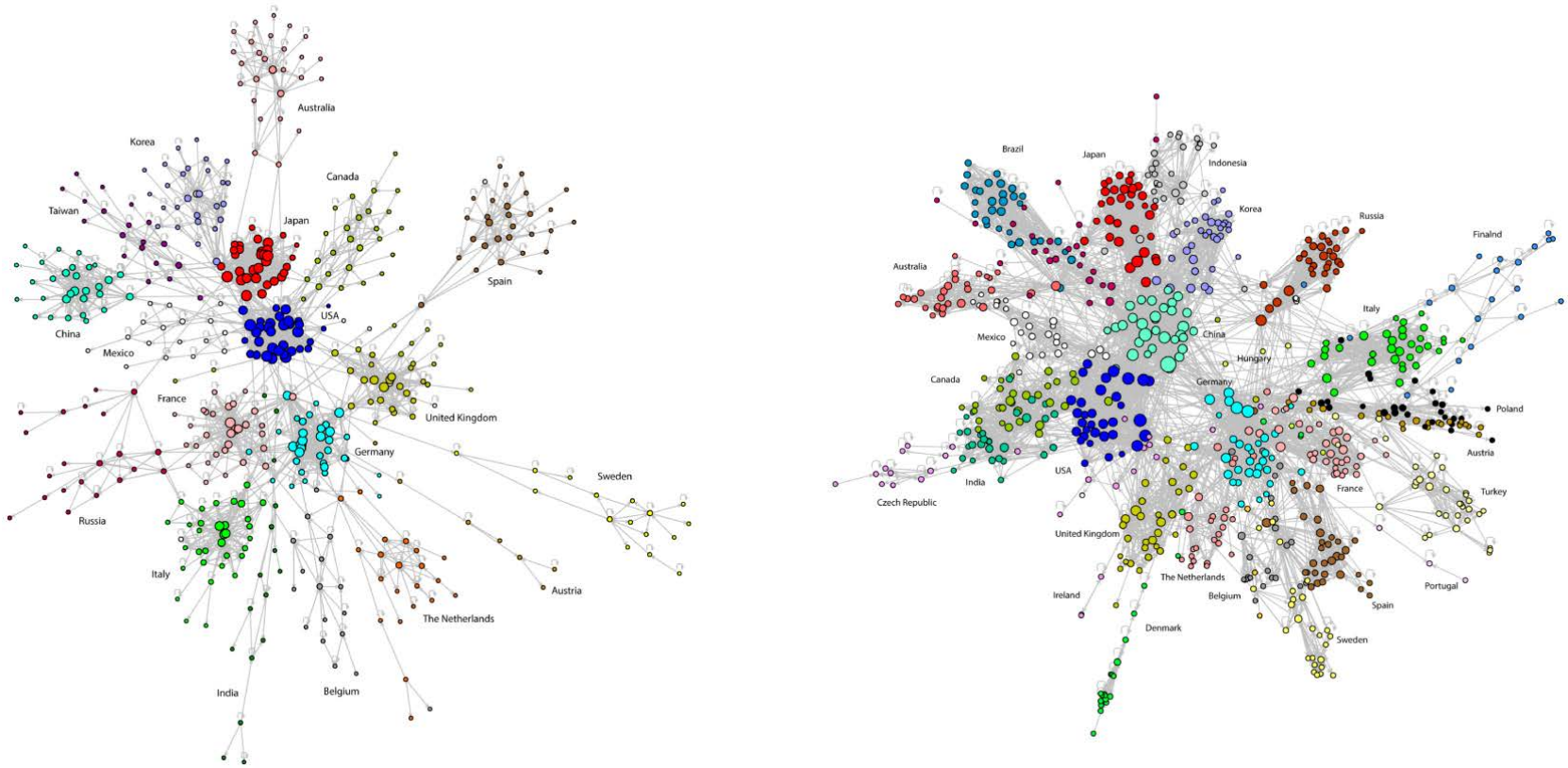
Results / Applications

Down to practical problems…

Infrastructure (CI) / Scenarios	Terrorist attack	Cyber attack	Extreme weather incl. NaTech events	IC-specific events	Cross-cutting issues
1. Smart cities (Germany, UK, Ireland)	✓	✓	(✓)	Social unrest, urban floods	Insurance, law enforcements, legislation, …
1. Smart health care (hospitals, Austria)	(✓)	✓	(✓)	Massive breach of privacy	
1. Smart energy supply systems (Finland)	✓	(✓)	(✓)	Solar storms (space weather)	
1. Smart industrial/production plants (new and refurbished plants, Industry 4.0 plants)	✓	✓	✓	Interruptions in the critical supply chains	
1. Smart transportation (airports; Hungary)	✓	✓	✓	Border control	

Use of Big Data

World Input Output Network



Supply-use network between sector X in country A and sector Y in country B, 1995 (left) and 2011 (right)

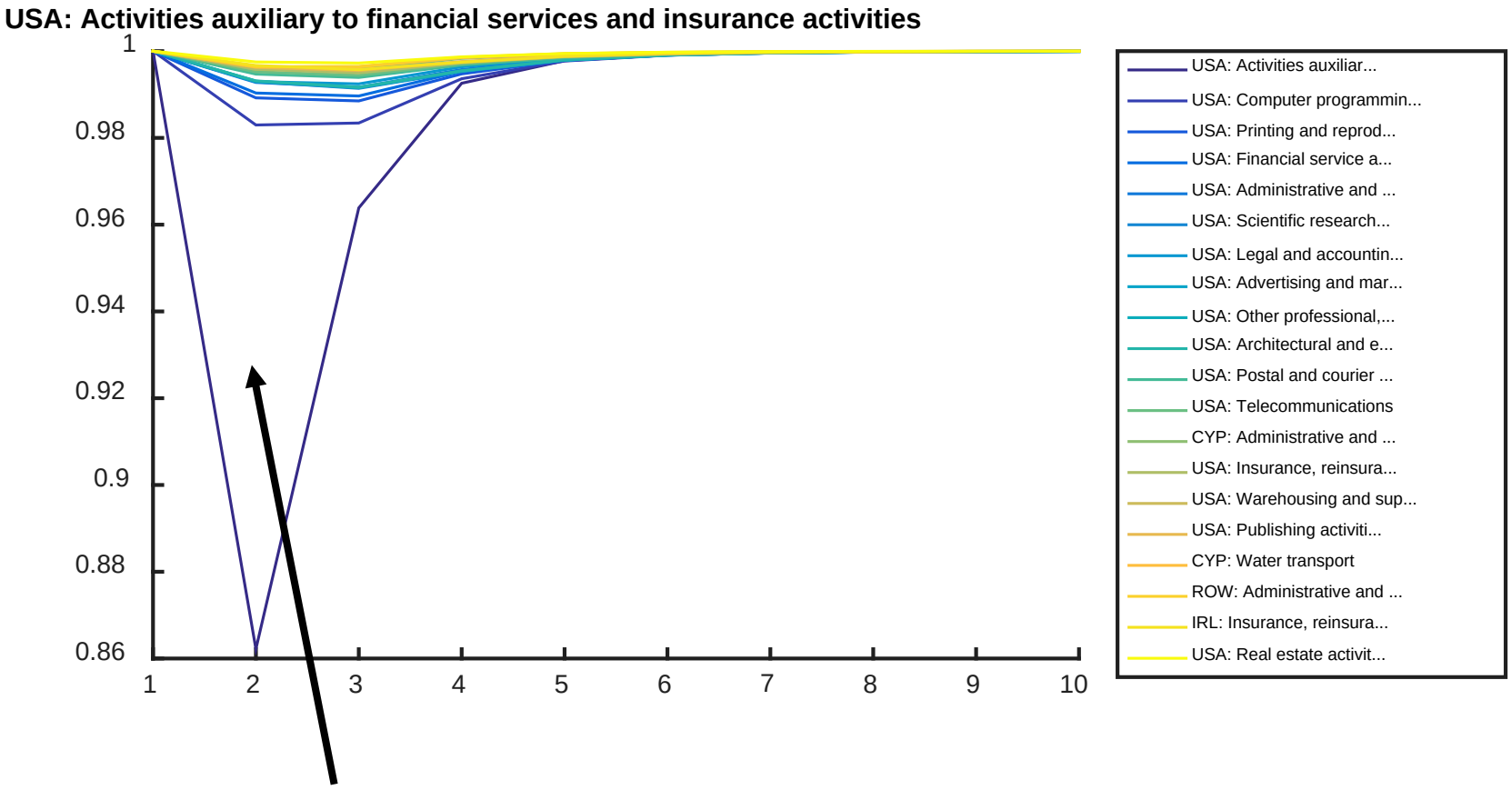
Cerina F, Zhu Z, Chessa A, Riccaboni M (2015) World Input-Output Network. PLoS ONE 10(7): e0134025. doi:10.1371/journal.pone.0134025

WIOD …

			Use by country-industries							Final use by countries			Total use
			Country 1			…	Country M			Country 1	…	Country M	
			Industry 1	…	Industry N	…	Industry 1	…	Industry N		…		
Supply from country-industries	Country 1	Industry 1											
		…											
		Industry N											
	……												
	Country M	Industry 1											
		…											
		Industry N											
Value added by labour and capital													
Gross output													

- X_i … Output („supply“) of sector *i*
- A_{ij} … Technical coefficient: € of input from sector *i* needed to produce € output in *j* (input-output network)
- D_i … Final consumption („use“) in sector *i*
- Assume standard Leontief economy: $X=AX+D$
- ***Absorb***: Apply shock δ to sector *k*: $B_{ij} = A_{ij}(1-\delta)$ if $i=k$ or $j=k$.
- ***Recover***: Assume that after shock there will be investments in rebuilding the infrastructure of size $\Sigma_j A_{kj}\delta$

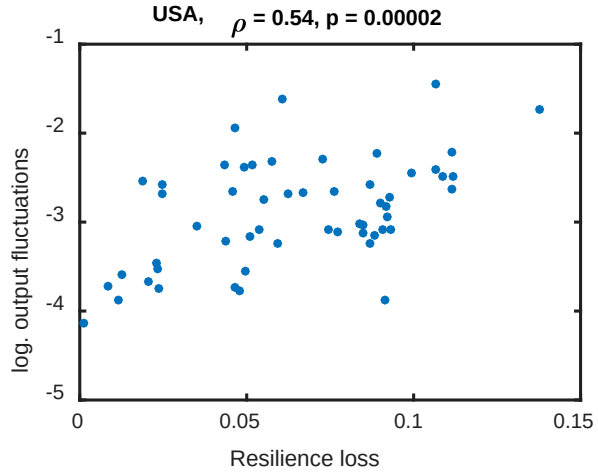
Example: Financial Crisis 2008

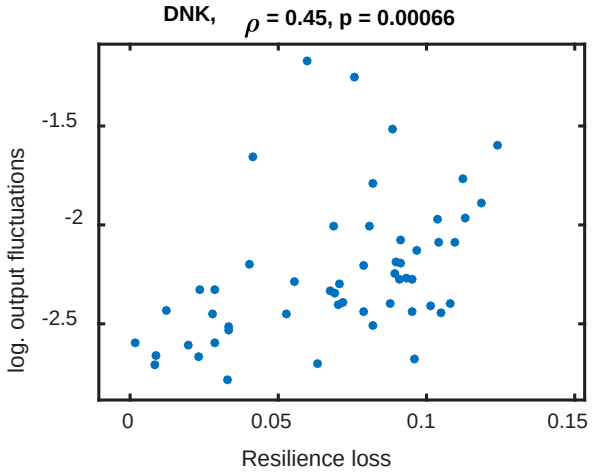


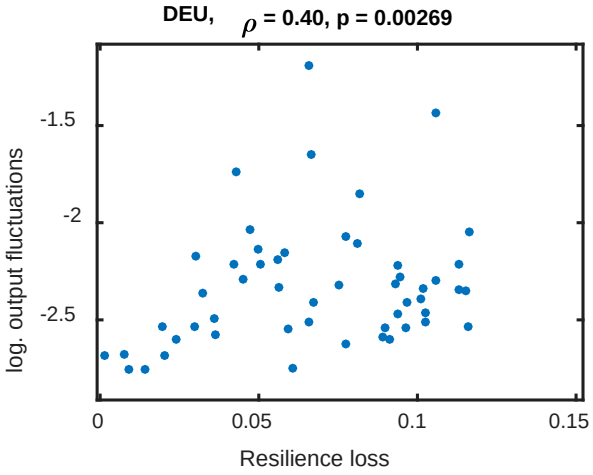
Area = resilience loss

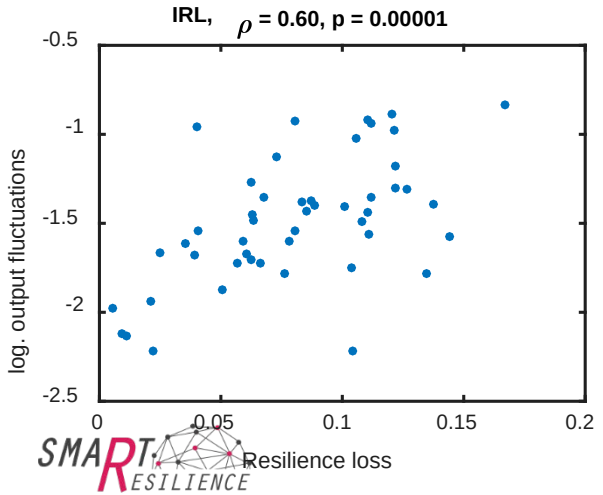
Validation of Resilience Indicators

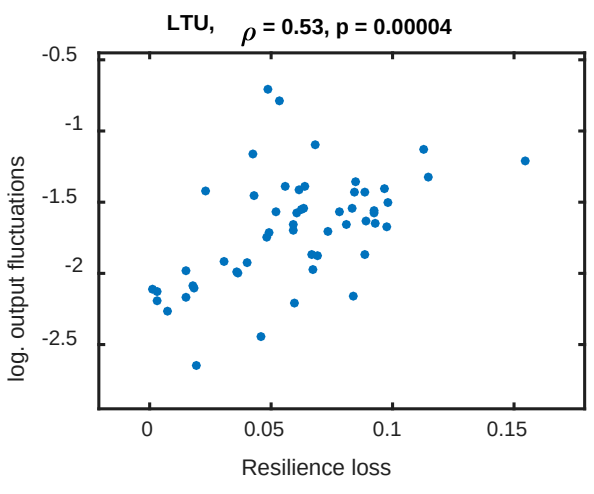
RIs are directly related to size of output fluctuations across individual sectors of a country!

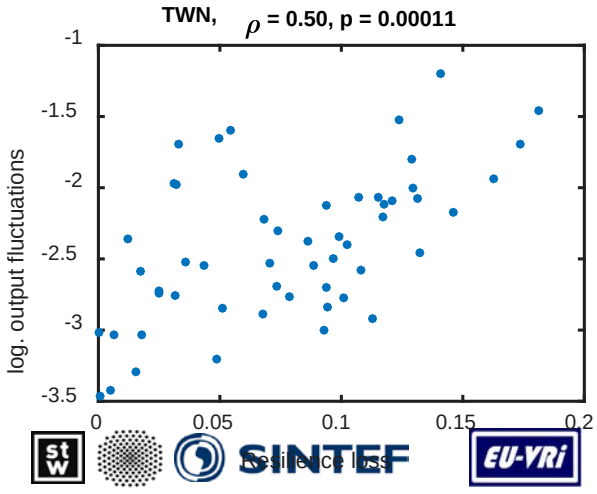




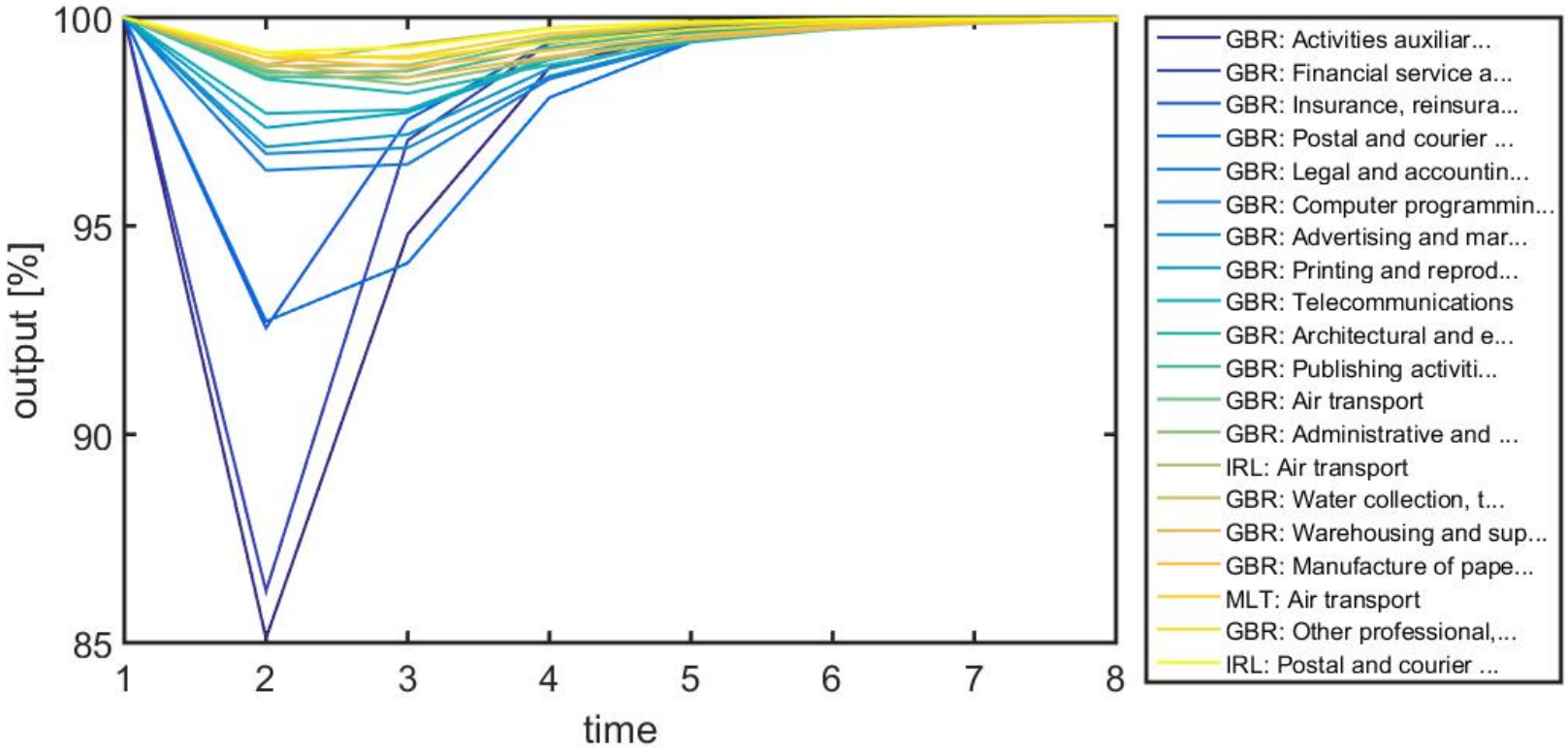




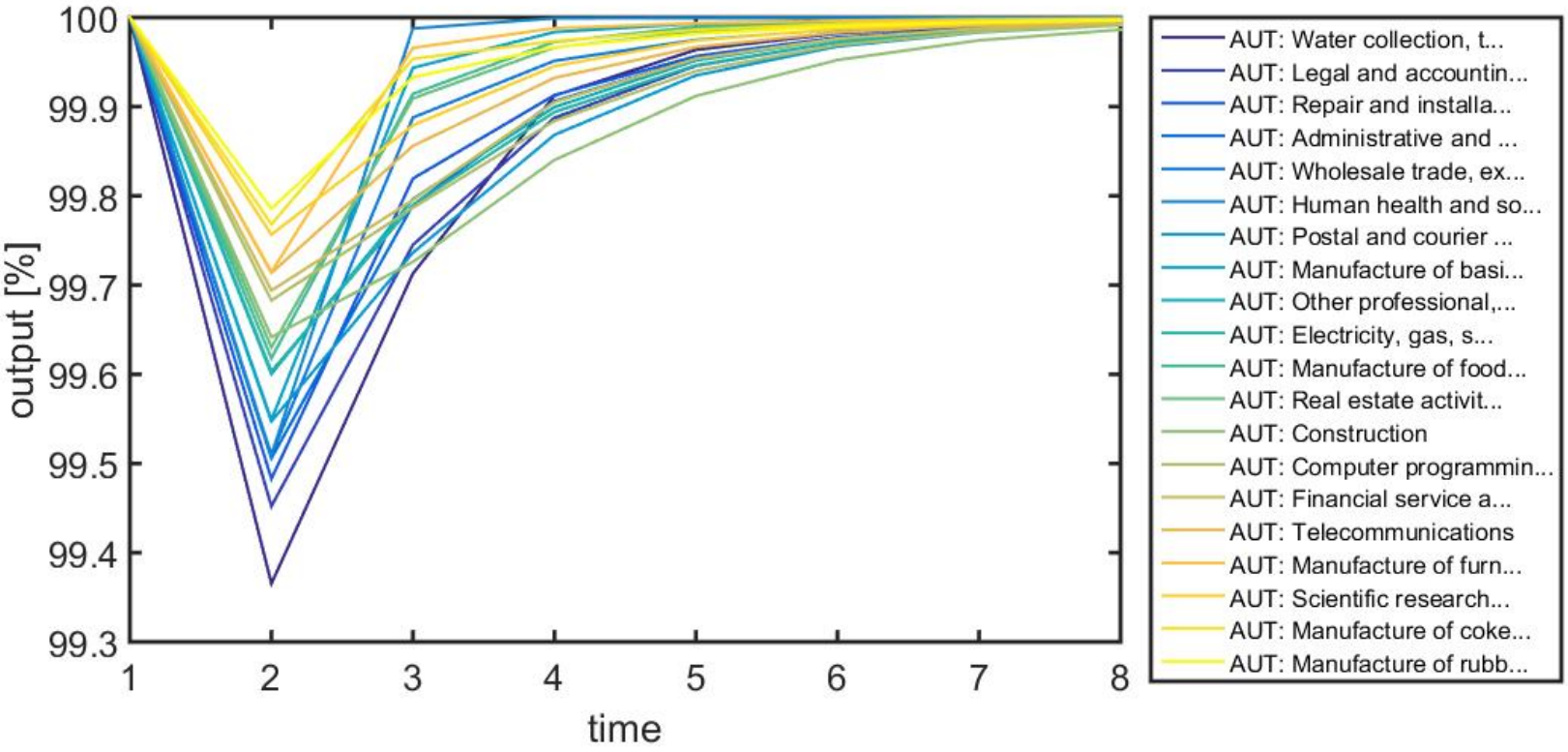




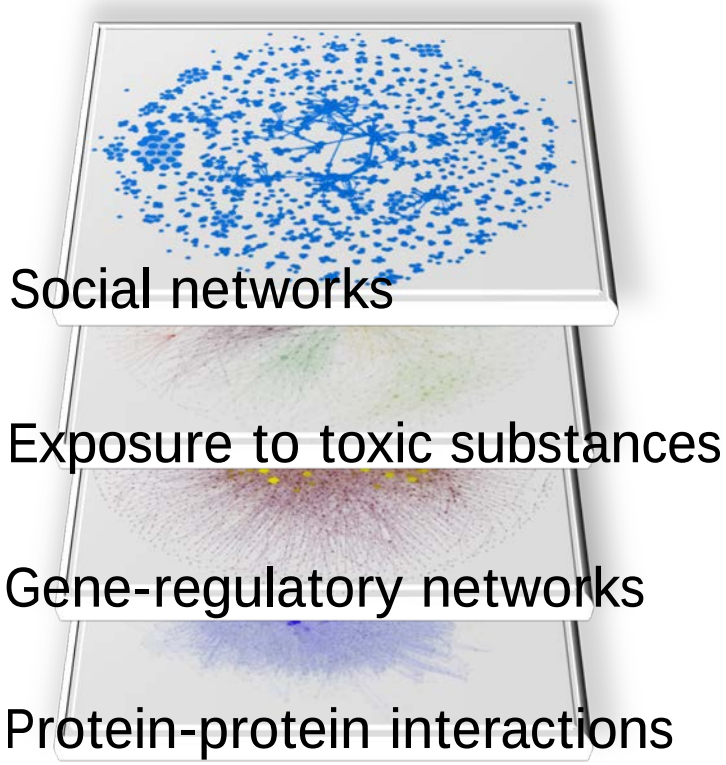
ALPHA: Financial infrastructure UK



CHARLIE: Health infrastructure Austria

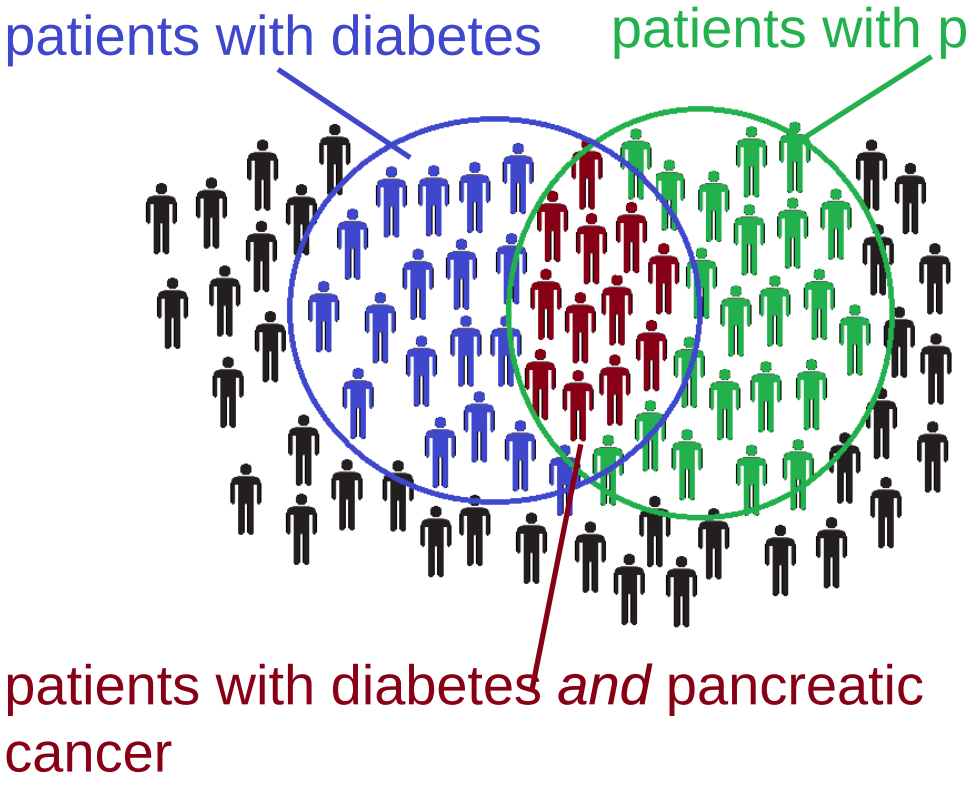


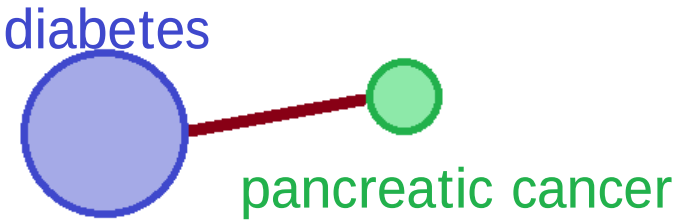
Multi-factorial diseases



- Multi-factorial diseases = consequences of defects in various types of networks that determine health
- Multimorbidity: one defect may increase risk for various diseases
- Need to understand these networks and how they influence each other to repair them
- ***„Next-generation phenotyping“***: a novel, data-driven and pathobiologically informed approach to understand human diseases and their interconnections

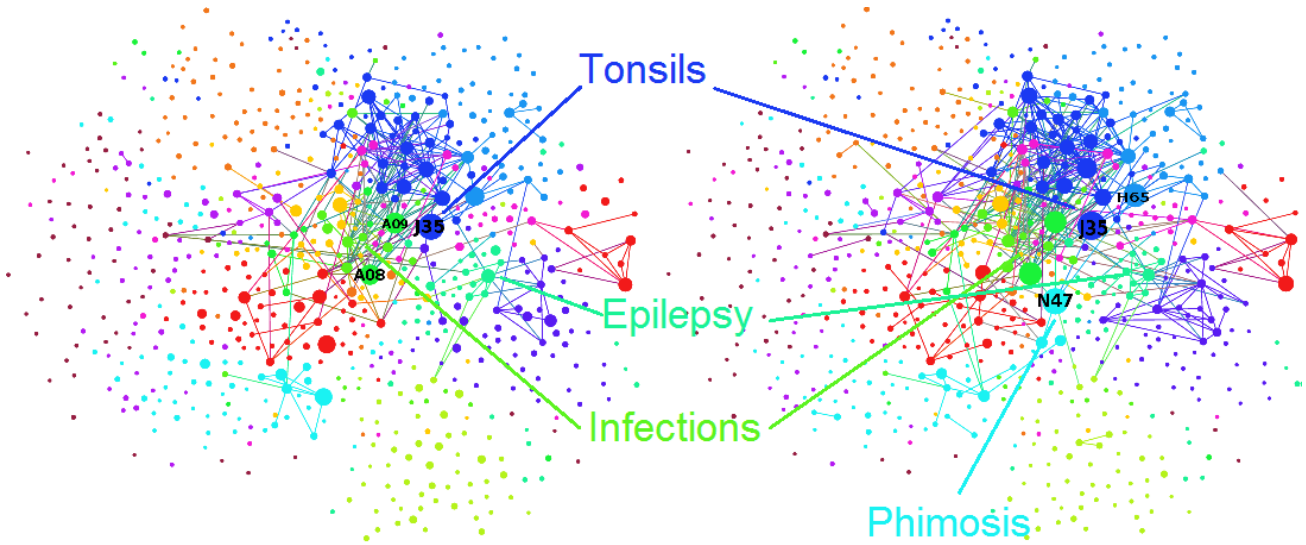
Comorbidity networks





- nodes = diseases
- links = diseases are often co-occurring
- size of nodes = disease prevalence

Comorbidity networks



females

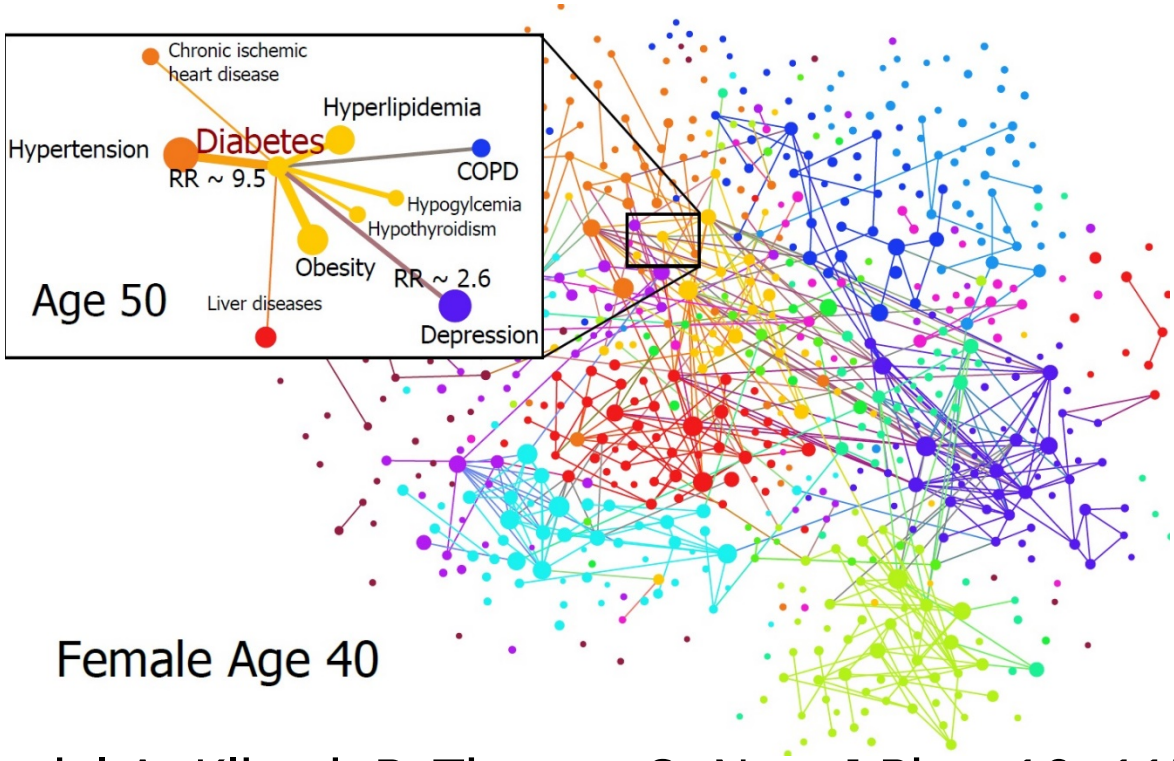
- A and B - Certain infectious
- C - Neoplasms
- D - Benign neoplasms and blood diseases
- E - Endocrine, nutritional and metabolic diseases
- F - Mental and behavioural disorders
- G - Diseases of the nervous system
- H - Diseases of the eye and ear

males

- I - Diseases of the circulatory system
- J - Diseases of the respiratory system
- K - Diseases of the digestive system
- L - Diseases of the skin and subcutaneous tissue
- M - Diseases of the musculoskeletal system
- N - Diseases of the genitourinary system

0-8 years
9-16 years
17-24 years
25-32 years
33-40 years
41-48 years
49-56 years
57-64 years
65-72 years

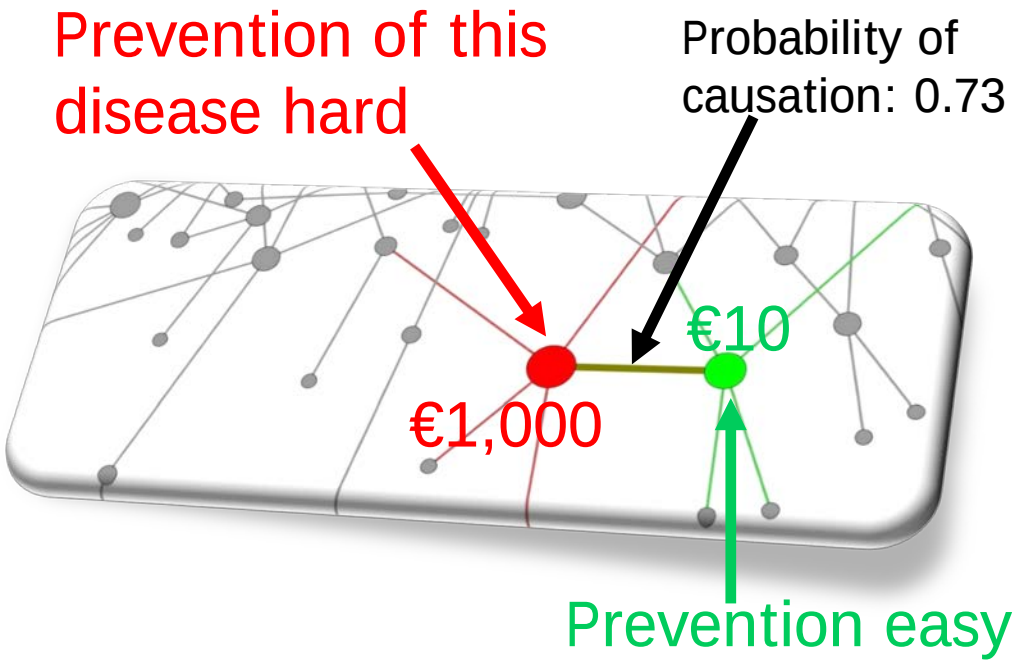
Predict incidences using comorbidity networks



population-wide forecast of 85%-95% of all disease incidences within the next ten life years

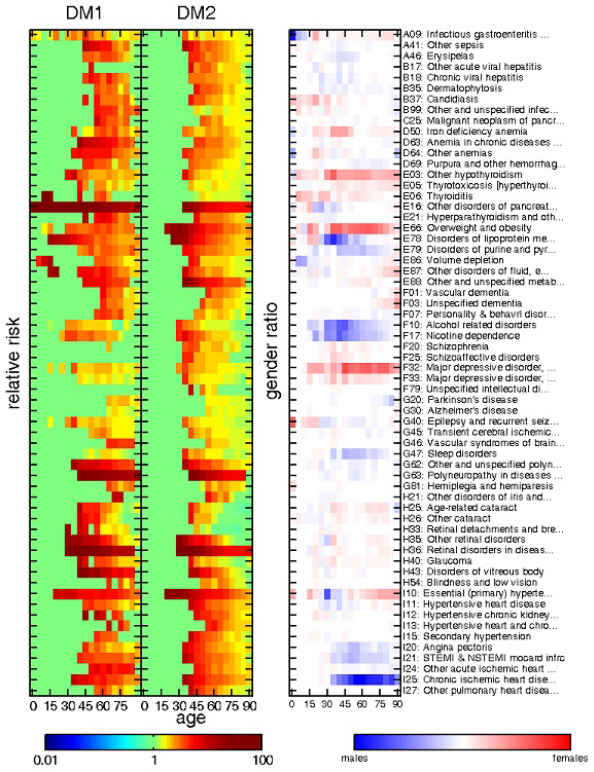
Chmiel A, Klimek P, Thurner S, New J Phys 16, 115013 (2014)

Comorbidity networks and prevention



Identify comorbidities→ Check causation→ Treat causing diseases

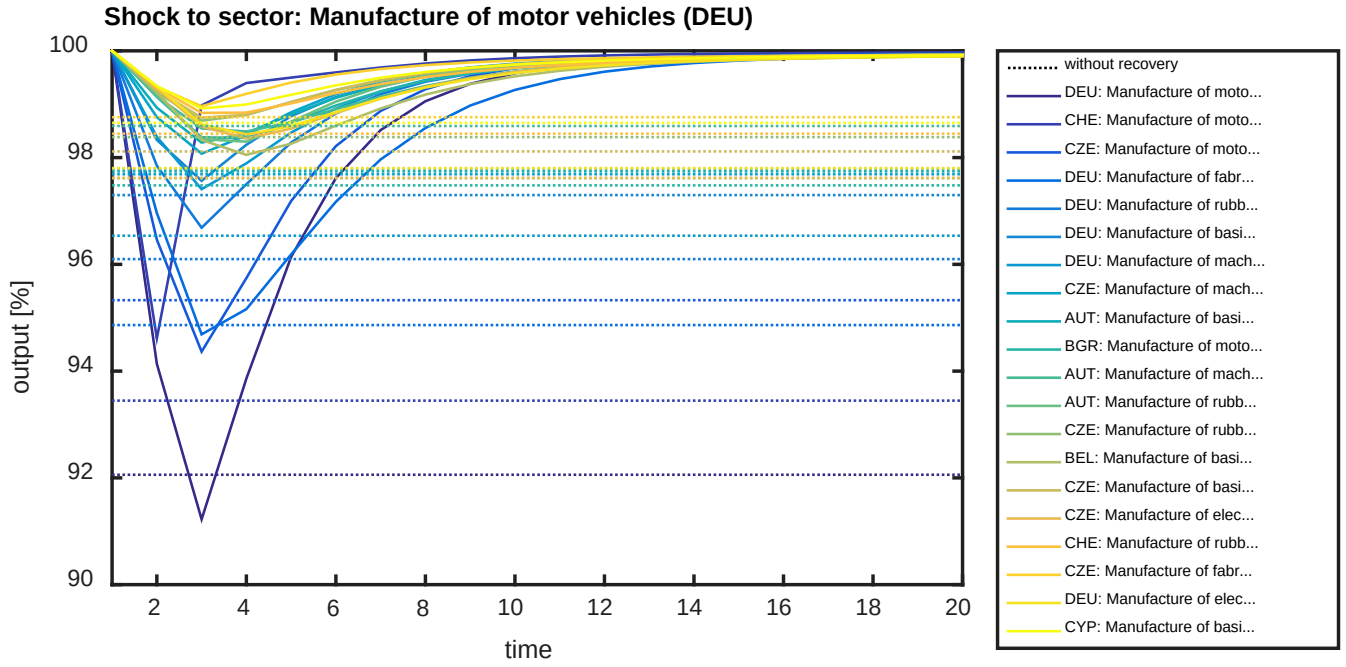
Zoom-In on diabetes: personalized health risks



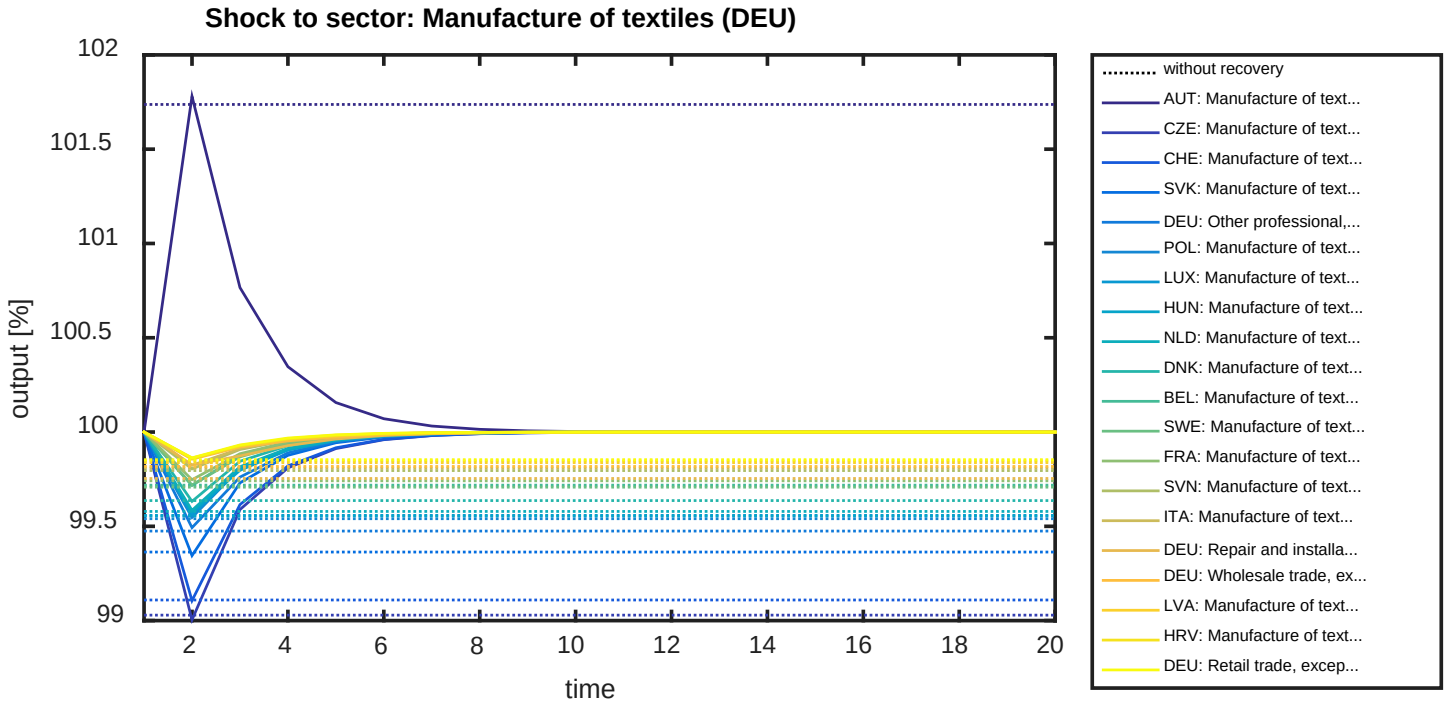
- Check diabetes for all possible known or unknown comorbidities – equivalent to 40k single epidemiological experiments → ≈100 highly significant comorbidities
- Confirmed controversial relation between diabetes and Parksinon‘s Disease.
- Strong gender effects: Lower risk for hypertension for females in fertile age, for example.
- Can partially check whether comorbidity relation is causative of consequential
- Type 1 diabetes typically present before onset of depressions.
- Schizo-affective disorders often lead type 2 diabetes → drug interaction?

Klimek P, Kautzky-Willer A, Chmiel A, Schiller-Frühwirt I, Thurner S, PLoS Comput Biol 11(4): e1004125 (2015)

Negative ripple effects within and to other countries



Shock in DEU -> AUT profits



Conclusions – Take away

Human thinking is (mainly!) 1-dimensional and linear

– resilience data are multi^{n}-dimensional and highly nonlinear

A (global) “bridge” is needed!

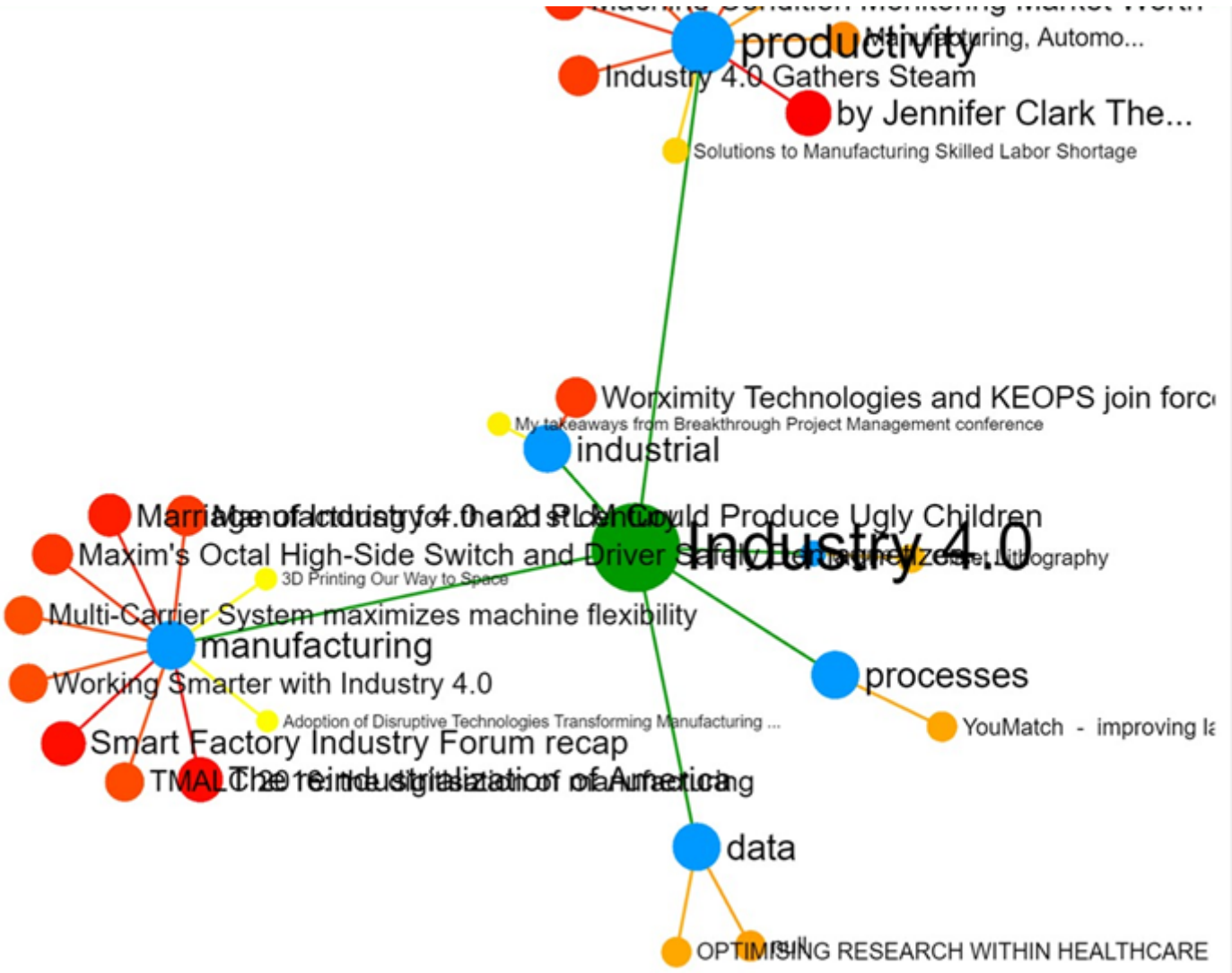
Practical Conclusions

- Give a new meaning to a SINGLE INDICATOR for RESILIENCE of an “infrastructure-of-infrastructures”
- Where are the indicators? Make clear how the network-based measures can be used as resilience indicators
- Visualization: align numbers with feeling (e.g. by means of intuitive visualization!)
- Make sure that the use of “big-data-indicators” will be aligned and integrated with the use of conventional indicators

Conclusions - Resilience: Emerging and Systemic Risks

- Challenge 0: In theory, we all talk about INTERdependencies, but, in practice, we hardly DEPENDENCIES
- Challenge 1: Intuitively, we incapable to understand the dependencies above "3rd level" and can have only a gut feeling about INTERdependencies. Visualization: can help to align numbers with feeling (e.g. intuitive visualization!)
- Challenge 2: The swarm of the black swans systemic risks!
- Challenge 3: How to make sure that the use of "big-data-indicators" is not misused (e.g. "used" for fake news)
- Challenge 4: Know the limits of methods and tools ("radars", including the big data ones!)
- Challenge 5: Know the limits: Sky/world are **NOT** always the right limit!

Conclusions: Resilience radar?



SMART RESILIENCE

SINTEF

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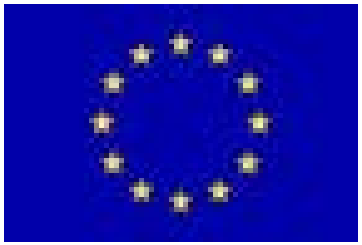
Legal note - Acknowledgment



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