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Comparing the Vulnerabilities of Semi-Centralized and Centralized Urban Water Systems in the Case of Qingdao, China

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Introduction of the Pilot Project in Qingdao

Implementation of the SEMIZENTRAL approach: The world's first Resource Recovery Center (RRC)

Background information about the Pilot Project in Qingdao:

- Emerging metropolis at China's east coast in ShanDong Province
- Fresh water resources are limited
- Rapid urban growth needs further water
- The Qingdao solution:
  - Seawater desalination
  - Energy demand: 3 - 4 kWh/m³
- The SEMIZENTRAL proposal:
  - Water reuse for < 1 kWh/m³

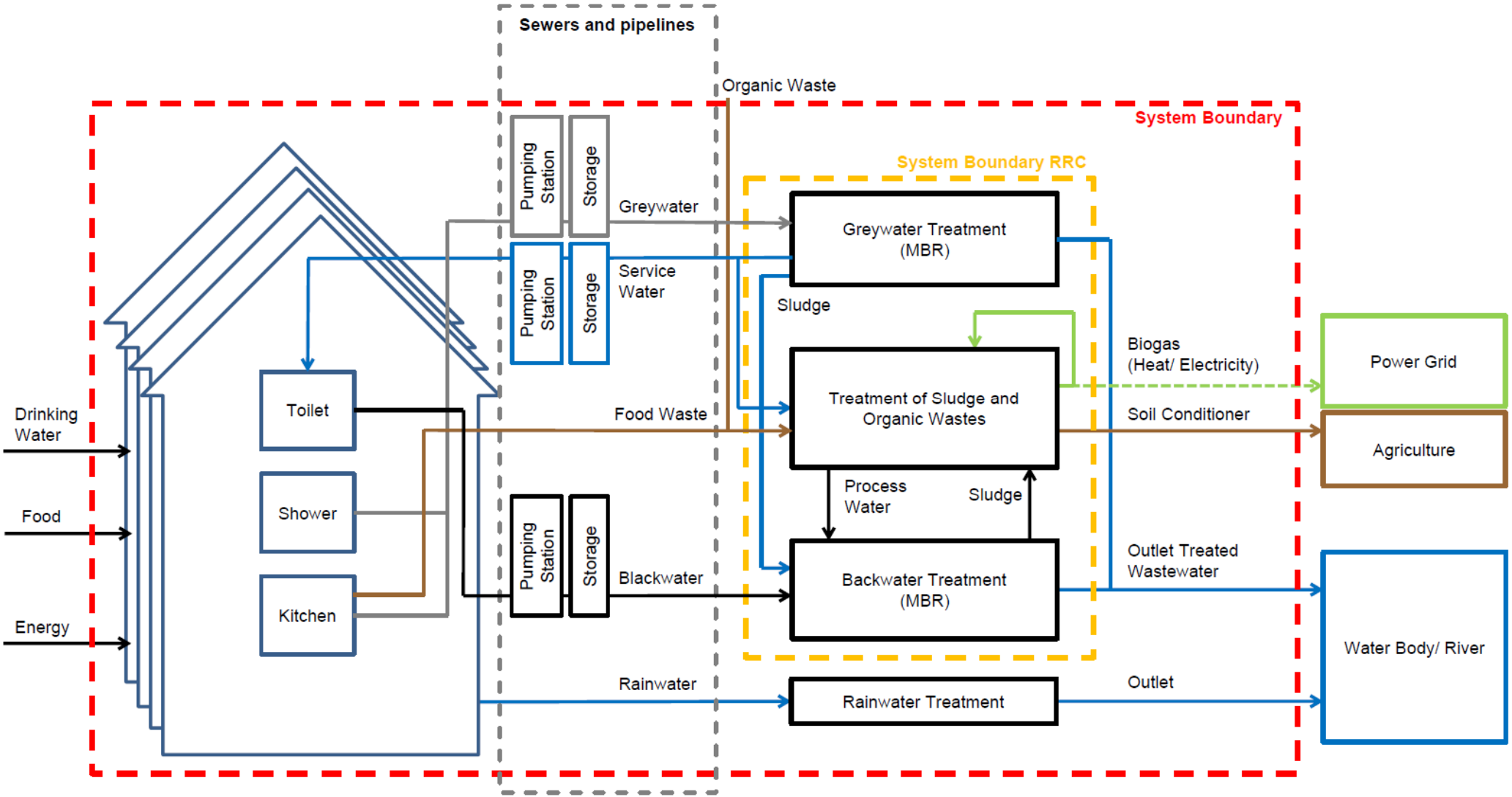
Introduction of the Pilot Project in Qingdao

SEMIZENTRAL GERMANY

- Capacity of about 12,000 PE
- Municipal wastewater from offices, residential areas, 3 hotels
- Separate collection and treatment of partial waste water flows
- Greywater reused as service water for toilet flushing
- Purified blackwater: irrigation of public green space
- Drinking water consumption reduced up to 30 percent
- Production of biogas using food waste and sewage sludge

Qingdao Water Group, 2016

Scheme of the Idealised SEMIZENTRAL System



Zimmermann et al., 2018

Research Objective and Methodology

- Objective:
  - Comparing the **vulnerability** (and resilience) of **centralized and novel water infrastructures** to internal and external **hazards** as well as their **dependencies** on other infrastructures
- Methodology:
  - Expert discussions, questionnaires and a vulnerability assessment heuristic
- Analysis was conducted for both systems:

	Semi-Centralized	Centralized
Population equivalents	12,000	69,000
Source separation	Yes	No
Water reuse	Yes	No
Biogas/ energy production	Yes	No

System Components and Hazards

SEMIZENTRAL GERMANY

- System components (reasonable functional units):
  - Within buildings (e.g. toilets, service water connections)
  - Sewers and pipelines in public space
  - Components of RRC or WWTP (e.g. greywater MBR)
- Hazards:
  - Internal hazards (e.g. human and technical failure)
  - External hazards (e.g. drought, heavy rainfall)
  - Dependencies on other infrastructures (e.g. on energy supply)

	Semi-Centralized	Centralized
System components	44	23
Hazards	28	24

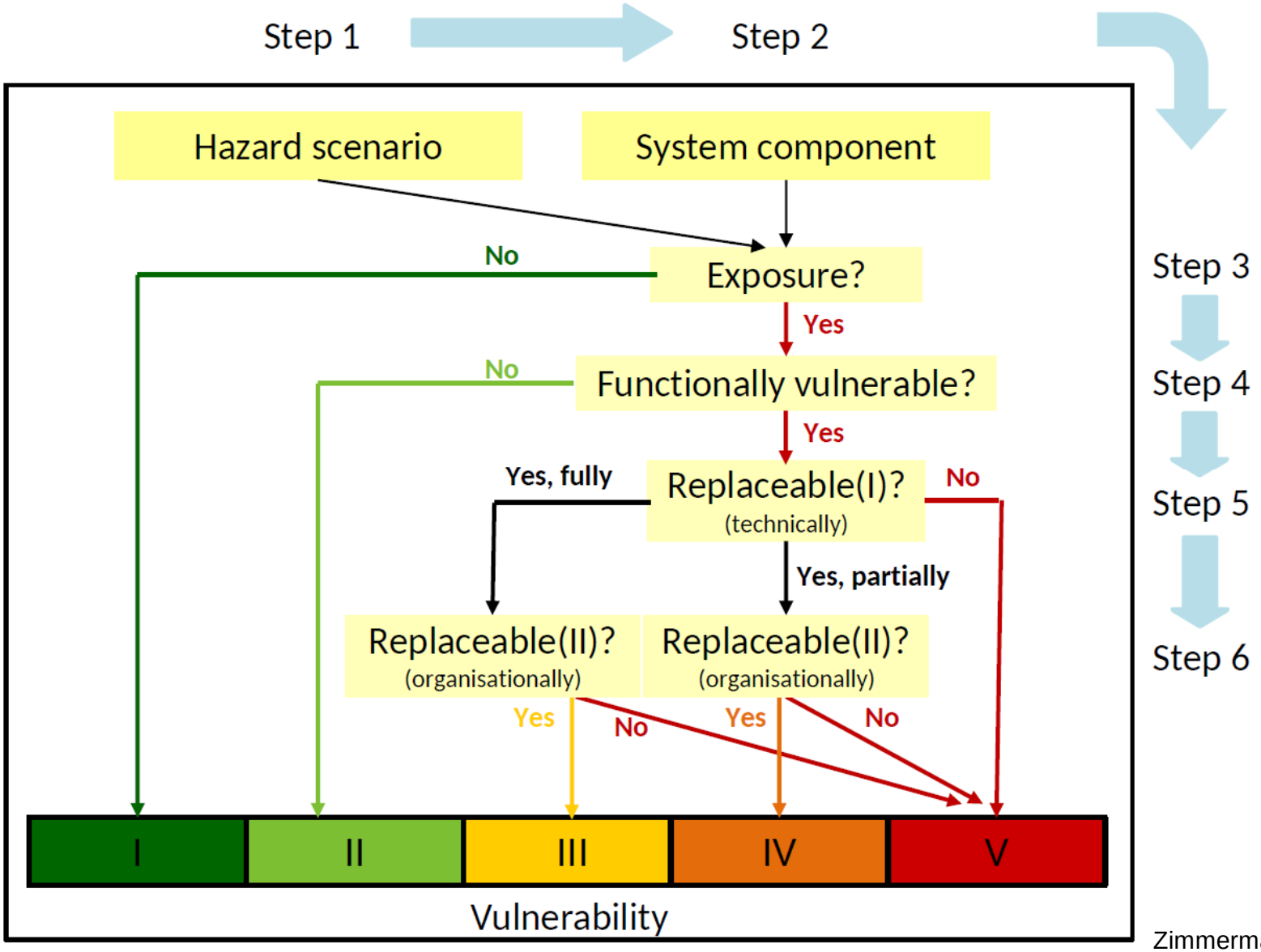
Vulnerability Matrix

SEMIZENTRAL GERMANY

- System components and hazards can be arranged in a vulnerability matrix
- Hazards were prioritized by experts regarding relevance
  (1 = “low priority” to 3 = “high priority”)
- Evaluation of the vulnerability matrix:
  - Impact of hazards → row sums
  - Vulnerability of system components → column sums

			Hotels						Residential and office areas						Water body	AC	Transmission pipelines												RRC																			
			GW		BW		SW		GW		BW		SW		SW/IW	IW	GW				BW				SW		IW			GW treatment					BW treatment						SW distribution		Energy module					
		Priority (3 = high, 2 = medium, 1 = low)	Connections (e.g. showers, sinks, washing machines)	Plumbing	Toilet connections	Plumbing	Toilet connections	Plumbing	Connections (e.g. showers, sinks, washing machines)	Plumbing	Toilet connections	Plumbing	Toilet connections	Plumbing	Outlet	Connection	Free-flow pipelines	Pressure pipelines	Pumping station	Reservoir	Free-flow pipelines	Pressure pipelines	Pumping station	Reservoir	Pipelines	Reservoir	Pipelines	Reservoir	Control system	Prestorage	Strainer	MBR: aeration/biolog. pretreatment	MBR: filtration (incl. backwashing tank)	Disinfection	Prestorage	Mech. pretreatment (sand trap, rack, primary treatment, strainer)	MBR: aeration/biolog. pretreatment	MBR: filtration (incl. backwashing tank)	(Activated carbon filter, not in use)	Disinfection	Reservoir	Pump	Waste pretreatment	Sludge and food waste treatment (fouling, drainage)	Process water treatment	Gas utilization	Zeilensumme (abs.)	Zeilensumme (gew.)
Internal	Technical failure (system component)	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	1	3	3	3	1	3	1	3	1	5	4	5	4	4	3	4	5	4	4	4	3	1	3	5	5	3	5	113	339
Internal	Technical failure (building)	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	113	339
Internal	Human failure	3	2	2	2	2	2	2	2	2	2	2	2	2	5	3	5	5	3	2	5	5	3	2	5	5	5	5	5	4	5	5	5	4	4	5	5	5	4	4	1	4	4	5	3	5	159	477
Internal	Extreme user numbers	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	1	2	1	2	4	5	5	4	2	4	5	5	3	3	2	2	1	2	2	2	104	104
Internal	Misuse by residents or hotel guests	2	1	2	1	2	2	1	1	2	1	2	2	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	1	2	2	2	2	1	2	2	2	2	1	1	1	1	1	1	1	1	66	132
Internal	Misuse by hotel operator	2	2	3	2	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	2	3	2	2	1	2	3	2	2	1	1	1	1	1	1	1	1	76	152
Internal	Wastewater cross connections	2	2	2	2	2	1	1	2	2	2	2	1	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	1	2	2	4	4	3	2	2	2	4	2	3	1	1	1	1	1	1	79	158
Internal	Cross connections of supply lines	3	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	64	192
Internal	Boycott of service water	1	1	1	2	4	2	2	1	1	1	1	2	2	1	2	1	1	1	1	4	4	4	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	69	69
Internal	Changing usage patterns	1	2	2	2	3	2	2	2	2	2	3	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	3	2	1	2	2	2	91	91
	Vandalism	2	2	2	2	2	2	2	2	2	2	2	2	2	5	4	1	1	4	2	1	1	4	2	1	5	1	5	5	2	3	4	4	3	2	3	4	4	3	3	5	3	2	5	3	3	122	244
External	Drought	1	2	2	2	4	2	2	2	2	2	4	2	2	2	2	2	2	2	2	4	4	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	1	1	92	92
External	Heavy rainfall	1	1	2	1	2	1	1	1	2	1	2	1	1	2	2	1	1	2	2	1	1	2	2	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	67	67
External	Landslide at RRC	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	112	336
External	Dam break	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	113	113
External	Earthquake	2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	220	440
External	Sabotage (e.g. terror, hacking)	2	1	1	1	1	1	1	1	1	1	1	1	1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	172	344
External	Fire	2	5	5	5	5	5	5	2	2	2	2	2	2	2	2	1	1	1	5	1	1	1	5	1	5	1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	164	328
External	Cold wave	1	1	1	1	1	1	1	1	1	1	1	1	1	4	5	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	67	67
External	Heat wave	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	4	2	1	1	2	2	87	87
External	Lightning strike, tornado	1	2	2	2	2	2	2	1	1	2	1	1	1	2	2	1	1	1	5	1	1	1	5	1	5	1	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	141	141
Dependencies	Drinking water supply	1	2	2	1	1	1	1	2	2	1	1	1	1	1	1	2	2	2	2	5	5	5	5	1	1	1	1	1	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	4	132	132
Dependencies	Energy	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	5	2	1	5	5	2	1	1	1	1	5	4	5	5	5	5	4	5	5	5	5	5	1	5	5	5	5	5	128	256
Dependencies	Delivery of food waste	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	2	3	5	55	110
Dependencies	Transport connection	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	3	3	3	2	2	3	3	2	3	2	2	5	3	2	2	97	97
Dependencies	Finances	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	220	660
Dependencies	Operating materials	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	5	5	5	1	5	5	5	5	5	5	5	1	5	5	2	97	194
Dependencies	Communication, IT	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	44	88
	Zeilensumme (abs.)		52	55	52	60	51	50	47	49	47	51	47	46	60	57	58	62	64	64	67	71	70	68	53	64	52	64	65	83	94	97	97	90	83	94	95	97	88	89	81	85	84	90	84	87		
	Zeilensumme (gew.)		98	103	98	108	96	94	89	92	89	94	89	87	112	104	115	123	124	117	124	132	130	121	104	119	103	119	134	161	183	186	186	171	161	183	182	186	170	170	148	164	166	178	163	173		

Heuristic for the Assignment of Vulnerability Classes (based on Krings 2013)



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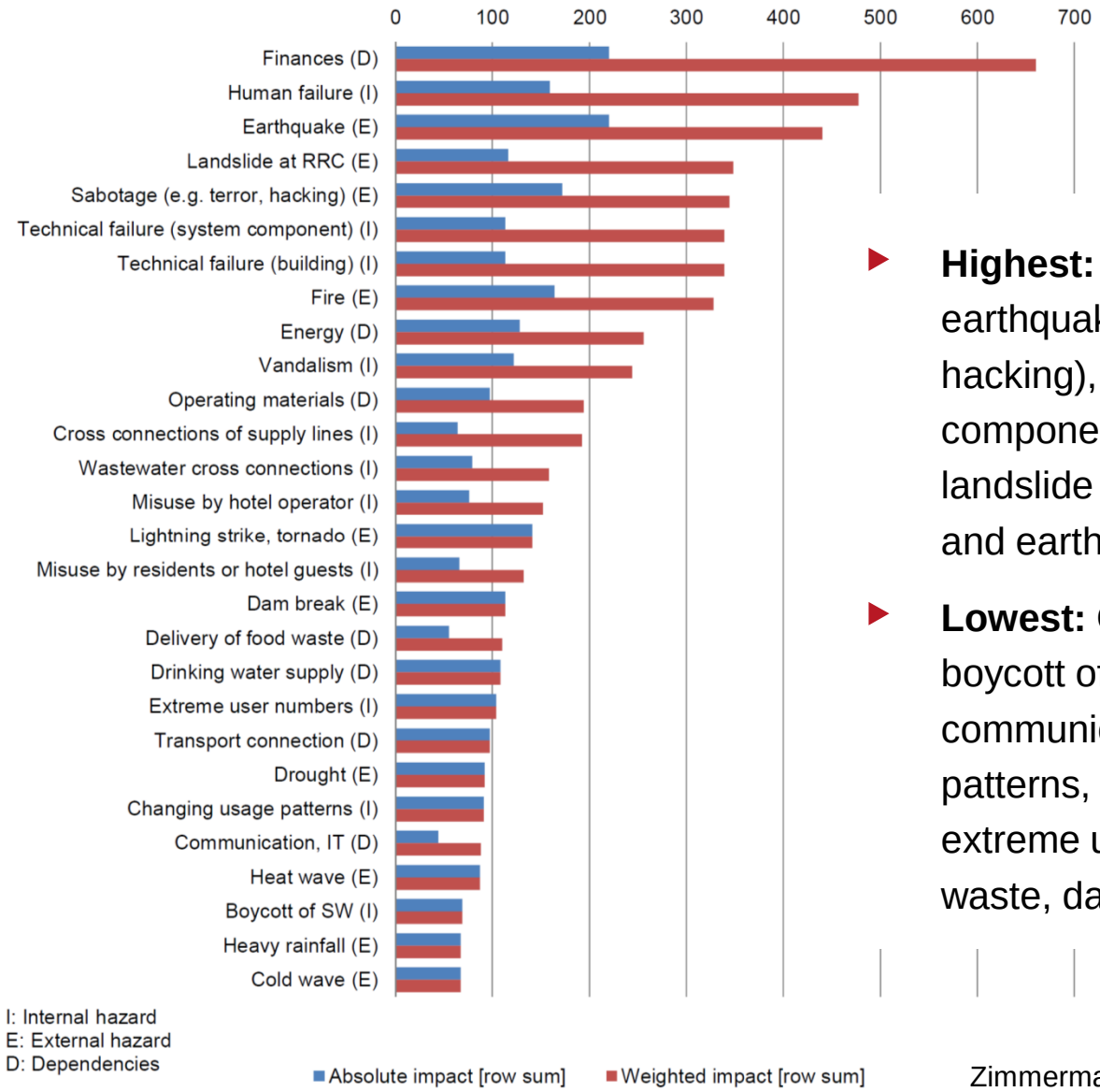
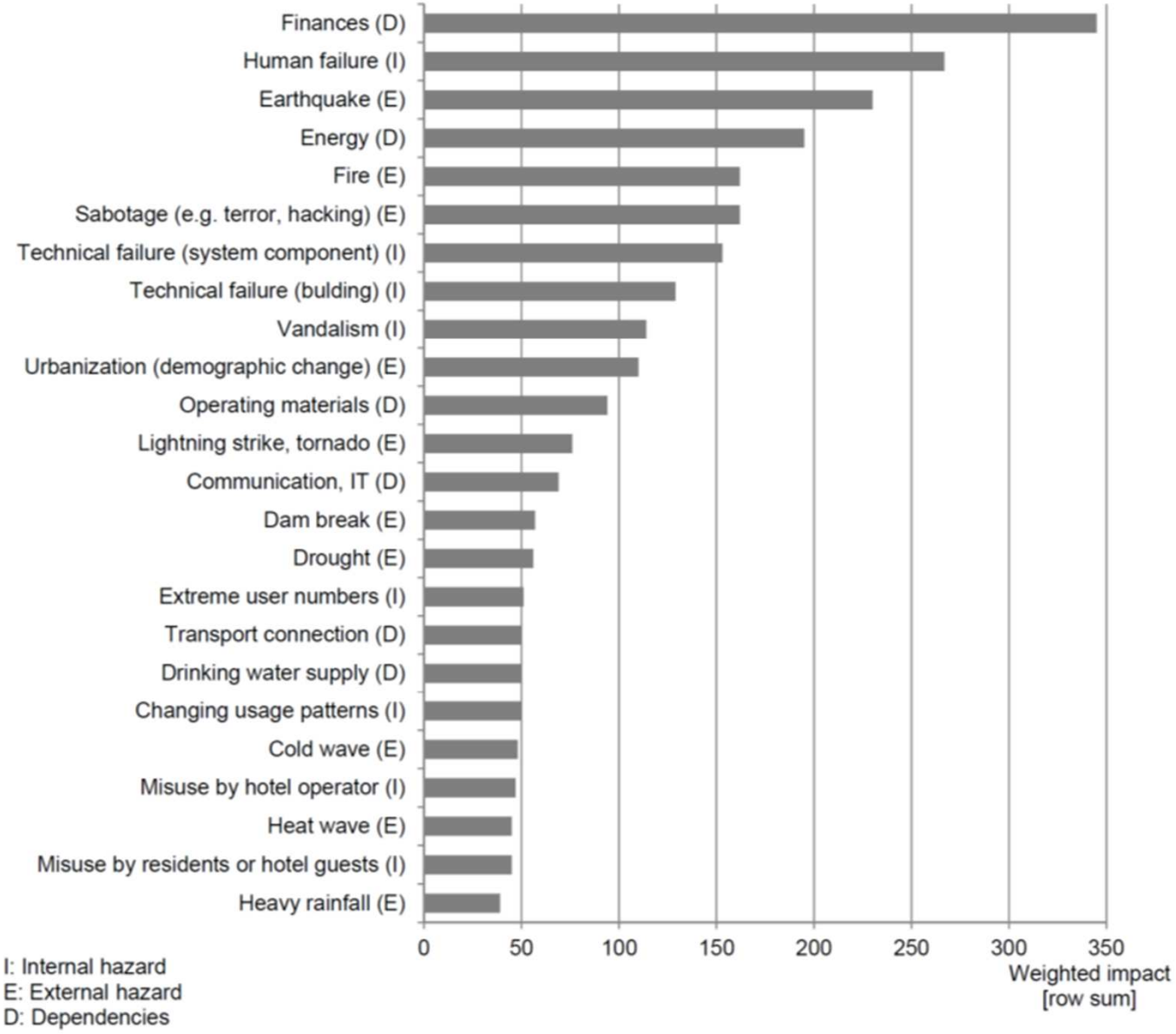
Impact of Hazards on the System's Vulnerability – Semi-Centralized System



- **Highest:** Finances, human failure, earthquakes, Sabotage (e.g. terror, hacking), technical failure (system component), technical failure (building), landslide RRC, fire (However, finances and earthquake are KO criteria.)
- **Lowest:** Cold wave, heavy rainfall, boycott of service water, heat wave, communication, IT, changing usage patterns, drought, transport connection, extreme user numbers, Delivery of food waste, dam break

Zimmermann et al., 2018

Impact of Hazards on the System's Vulnerability – Centralized System



- **Highest:**
  finances, human failures, earthquakes, energy, fire, sabotage (e.g. terror), technical failures (system components)
- **Lowest:**
  heavy rainfall, misuse by residents or hotel guests, heat wave, cold wave, changing usage patterns, drinking water supply

Results (1): Impact of Hazards

- In both cases:
  - Hazards with **highest impact**: human failure, sabotage, technical failure, fire
  - KO criteria: earthquakes, finances
  - Hazards with **lowest impact**: natural hazards (cold waves, heavy rainfall, heat waves, droughts), dependencies (e.g. transport, drinking water)
- Advantages of semi-centralized systems:
  - Less affected by external hazards (e.g. natural hazards: droughts, cold waves)
  - Better compensation of extremes in the number of users (e.g. due to holidays or events) and changes in the patterns of use (e.g. changing drinking or service water consumption)
  - Higher independency on other infrastructures (e.g. energy supply and communication/IT)
- Disadvantage of semi-centralized systems:
  - More affected by internal hazards (e.g. technical failure and misuse)

Results (2)

- Dependency of system components on hazards in both cases:
  - RRC and WWTP components more susceptible to hazards
  - Components in buildings least dependent
  - Sewers and pipelines show a medium dependency
  - → Reason: local hazards may harm RRC/WWTP components, but unlikely for whole service area
- General remarks regarding semi-centralized systems:
  - 5 to 6 semi-centralized systems required for appropriate comparison
  - Modular arrangement makes them **more robust** against hazards
  - Can **adapt more flexibly** to changing conditions (e.g. population growth)
  - **More cost-effective** since investments can be made according to growth

Conclusions

- Vulnerability analysis identified strengths and weaknesses of both systems
- Results contribute to:
  - Better planning and operation of urban water systems
  - Future replications of semi-centralized systems
- Vulnerability management needs to focus on minimizing vulnerability by:
  - Preventing hazards that can be influenced (e.g. cross connections)
  - Strengthening resilience of system components
- Next steps:
  - Analysis of effects of system components' failures on vulnerability
  - Identification of system components susceptible to failure of other components

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